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Environmental Regulations and Technology
Use and Disposal of Municipal Wastewater Sludge

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Cincinnati, OH

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This guidance document describes the five major sludge use/disposal options currently available--land application, distribution and marketing of sludge products, landfilling, incineration, and ocean disposal--and factors influencing their selection and implementation. It is intended for a broad audience of individuals and organizations, including state and local officials, managers and operations of wastewater treatment systems, planners, resource managers, and concerned citizen groups. It also provides an initial framework for evaluating sludge use/disposal alternatives, and describes accepted and proven use/disposal technologies and Federal regulations pertinent to sludge management.

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Use and Disposal of Municipal Wastewater Sludge

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Washington DC 20460

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COVER PHOTOGRAPH: Municipal wastewater sludge compost.

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Abbreviations

ac = acre
BTU = British thermal unit
cm = centimeter
cu yd = cubic yard
°C = degree Celsius
°F = degree Fahrenheit
ft = foot
gal = gallon
ha = hectare
hr = hour
in = inch
kg = kilogram
kJ = kilojoule
km = kilometer
kW = kilowatt
l = liter
lb = pound
m = meter
m^3 = cubic meter
mil gal = million gallons
meq = milliequivalent
mg = milligram
mgd = million gallons per day
mi = mile
mt = metric ton
no = number
ppm = parts per million
sq ft = square feet
yr = year
% = percent
$ = dollar

1. Introduction

The Clean Water Act requires municipalities to cleanse their wastewaters prior to discharging them into the environment. This cleansing process—wastewater treatment—generates sludge which in turn must be used or disposed of. Sludge management begins with sludge generation and continues through sludge treatment and sludge use and disposal (Figure 1). It is an integral consideration in the planning and design of wastewater treatment plants, and can be the most complex and costly part of wastewater management. This document provides guidance on the final step in the sludge management process—the ultimate use and disposal of municipal wastewater sludge.

The need for effective sludge management is continual and growing. The quantity of municipal sludge produced annually has almost doubled since 1972, when the Clean Water Act imposed uniform minimum treatment requirements for municipal wastewater. In addition, the sludges generated by more advanced treatment are more difficult to handle than the sludges produced by less advanced treatment. Municipalities currently generate approximately 6.2 million dry metric tons (mt) (6.5 million dry tons) of wastewater sludge a year, or approximately 26 kilograms (kg) (56 dry pounds [lb]) per person per year. Sludge production is expected to about double to approximately 12 million dry mt (13 million dry tons) per year by the year 2000 as the population increases, as more municipalities comply with Clean Water Act requirements, and as more sophisticated wastewater treatment systems are developed and installed.

When properly used, sludge can be a valuable resource as a soil conditioner and partial fertilizer and as a source of methane for producing energy. The U.S. Environmental Protection Agency (EPA), the primary Federal regulatory agency responsible for sludge management, encourages the beneficial use of sludge wherever environmentally feasible (Figure 2).

This guidance document describes the five major sludge use/disposal options currently available—land application, distribution and marketing of sludge products, landfilling, incineration, and ocean disposal—and factors influencing their selection and implementation. The document is intended for a broad audience of individuals and organizations, including state and local officials, managers and operators of wastewater treatment systems, planners, resource managers, and concerned citizen groups.

The document provides an initial framework for evaluating sludge use/disposal alternatives. It describes accepted and proven use/disposal technologies and Federal regulations pertinent to sludge management (Table 1). Additional sources must be consulted for more detailed information and design criteria, and for the most current information on emerging technologies. In addition, state and local authorities should be consulted to determine regulations and good management practices applicable to local areas.

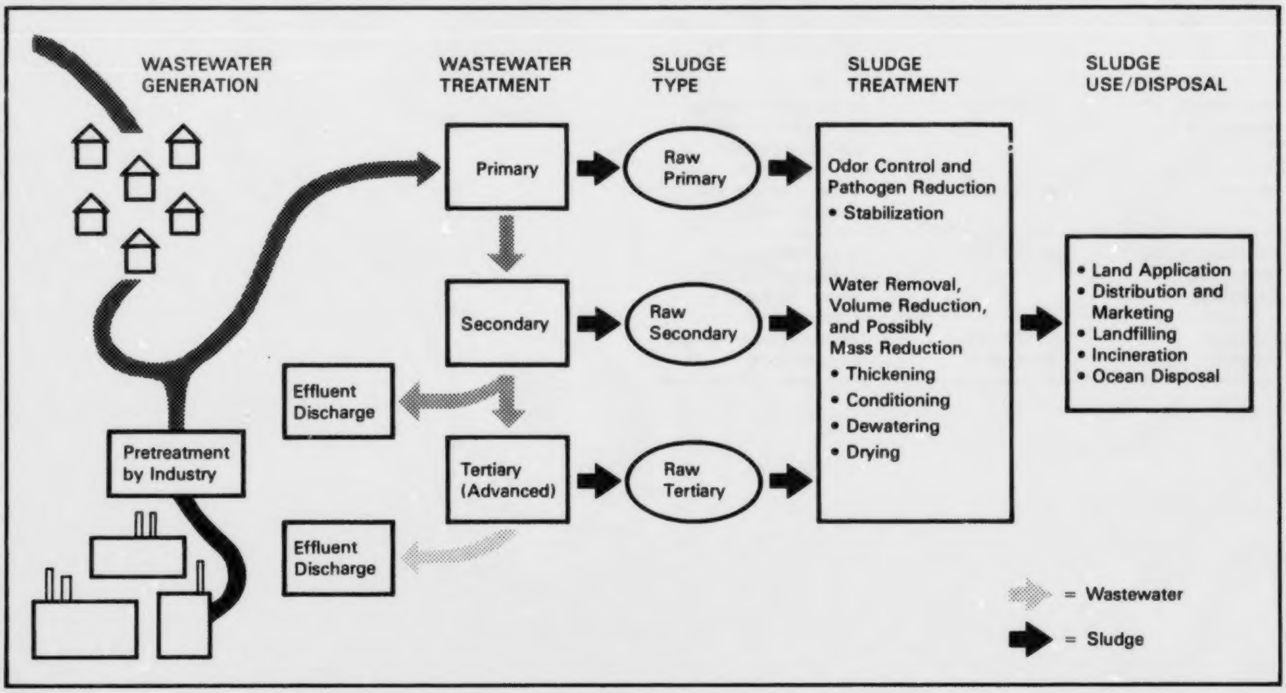

WASTEWATER GENERATION
WASTEWATER TREATMENT
SLUDGE TYPE
SLUDGE TREATMENT
SLUDGE USE/DISPOSAL
Primary
Secondary
Tertiary (Advanced)
Raw Primary
Raw Secondary
Raw Tertiary
Odor Control and Pathogen Reduction
• Stabilization
Water Removal, Volume Reduction, and Possibly Mass Reduction
• Thickening
• Conditioning
• Dewatering
• Drying
• Land Application
• Distribution and Marketing
• Landfilling
• Incineration
• Ocean Disposal
Effluent Discharge
Effluent Discharge
Pretreatment by Industry
= Wastewater
= Sludge

Figure 1. Generation, Treatment, and Disposal of Municipal Wastewater Sludge

> The U.S. Environmental Protection Agency (EPA) will actively promote those municipal sludge management practices that provide for the beneficial use of sludge while maintaining or improving environmental quality and protecting public health. To implement this policy, EPA will continue to issue regulations that protect public health and other environmental values. The Agency will require states to establish and maintain programs to ensure that local governments utilize sludge management techniques that are consistent with Federal and state regulations and guidelines. Local communities will remain responsible for choosing among alternative programs; for planning, constructing, and operating facilities to meet their needs; and for ensuring the continuing availability of adequate and acceptable disposal or use capacity.
>
> SOURCE: Reference (1).

Figure 2. EPA Policy on Municipal Sludge Management

Table 1. Sludge Management Regulations of the U.S. Environmental Protection Agency

Coverage	Reference	Application
Polychlorinated Biphenyls (PCBs)	40 CFR 761	All sludges containing more than 50 milligrams per kilogram
Ocean Dumping	40 CFR 220-228	The discharge of sludge from barges or other vessels
New Sources of Air Emissions	40 CFR 60	Incineration of sludge at rates above 1,000 kilograms per day
Mercury	40 CFR 61	Incineration and heat drying of sludge
Cadmium, PCBs, Pathogenic Organisms	40 CFR 257	Land application of sludge, landfills, and storage lagoons
Extraction Procedure Toxicity	40 CFR 261 Appendix II	Defines whether sludges are hazardous

This document has 11 chapters. Chapter 2, *Municipal Wastewater Sludge*, describes the different types of municipal sludges and how their characteristics affect their suitability for various use/disposal options. Chapters 3 through 7 present the five basic sludge use/disposal options: *Land Application, Distribution and Marketing of Sludge Products, Landfilling, Incineration,* and *Ocean Disposal*. Chapter 8, *Evaluating Alternatives*, describes key factors involved in evaluating the sludge use/disposal alternatives. Chapter 9 discusses *Trends and Prospects* in sludge use/disposal, Chapter 10 presents *Sources of Further Information*, and Chapter 11 lists *References*.

2. Municipal Wastewater Sludge

2.1 What Is Wastewater Sludge?

Sludge is a by-product of municipal wastewater treatment. It usually contains 93 to 99.5 percent water as well as solids and dissolved substances that were present in the wastewater and that were added or cultured by wastewater treatment processes. Usually these wastewater solids are treated prior to ultimate use/disposal to improve their characteristics for these processes (Figure 1 and Table 2).

The characteristics of a sludge depend on both the initial wastewater composition and the subsequent wastewater and sludge treatment processes used. Different treatment processes generate radically different types and volumes of sludge (Figure 3 and Table 2). At an individual plant, the characteristics of the sludge produced can vary annually, seasonally, or even daily because of variations in incoming wastewater composition and variations in the treatment processes. This variation is particularly pronounced in wastewater systems that receive a large proportion of industrial discharges.

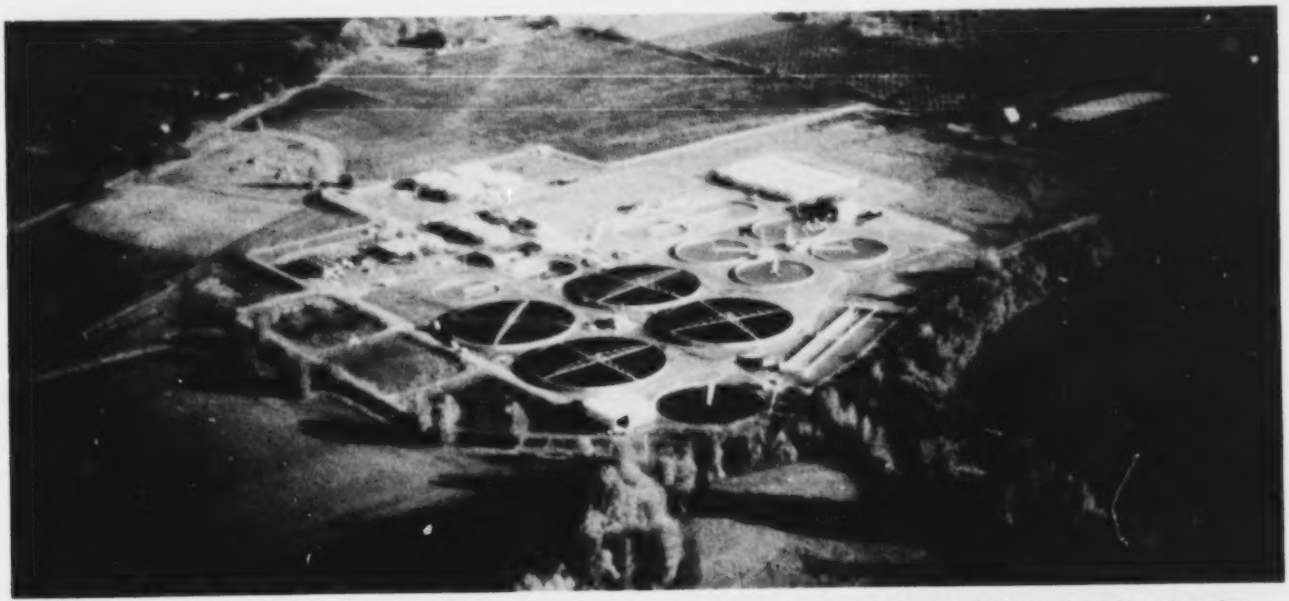
The characteristics of a sludge affect its suitability for the various use/disposal options. Thus, when evaluating sludge use/disposal alternatives, a municipality should first determine the amount and characteristics of its sludge and the degree of variation in these characteristics.

PRIMARY SLUDGE. Generated during primary wastewater treatment, which removes the solids that settle out readily. Primary sludge contains 3 to 7 percent solids; usually its water content can be easily reduced by thickening or dewatering.

SECONDARY SLUDGE. Often called *biological process sludge* because it is generated by secondary biological treatment processes, including activated sludge systems and attached growth systems such as trickling filters. Secondary sludge has a low solids content (0.5 to 2 percent) and is more difficult to thicken and dewater than primary sludge.

TERTIARY SLUDGE. Produced by advanced wastewater treatment processes, such as chemical precipitation and filtration. The characteristics of tertiary sludge depend on the wastewater treatment process that produced it. *Chemical sludges* result from treatment processes that add chemicals, such as lime, organic polymers, and aluminum and iron salts, to wastewater. Generally, lime or polymers improve the thickening and dewatering characteristics of a sludge, whereas iron or aluminum salts usually reduce its dewatering and thickening capacity by producing very hydrous sludges which bind water.

Figure 3. Types of Raw (Untreated) Sludge



A typical wastewater treatment plant. Municipal wastewater enters through the rectangular pre-aeration basin on the right and receives primary treatment in a clarifier (bottom center). Four large trickling filters (center) provide secondary treatment, and six clarifiers (top right) remove the solids formed by secondary treatment before discharging the clarified water to the pond on far right. Sludges from the primary and secondary clarifiers are thickened in the two smaller circular tanks just above the trickling filters, then pumped to digesters (upper left) and, from there, to one of the three storage lagoons (center left).

Table 2. Effects of Pretreatment and Sludge Treatment Processes on Sludge and Sludge Use / Disposal Options

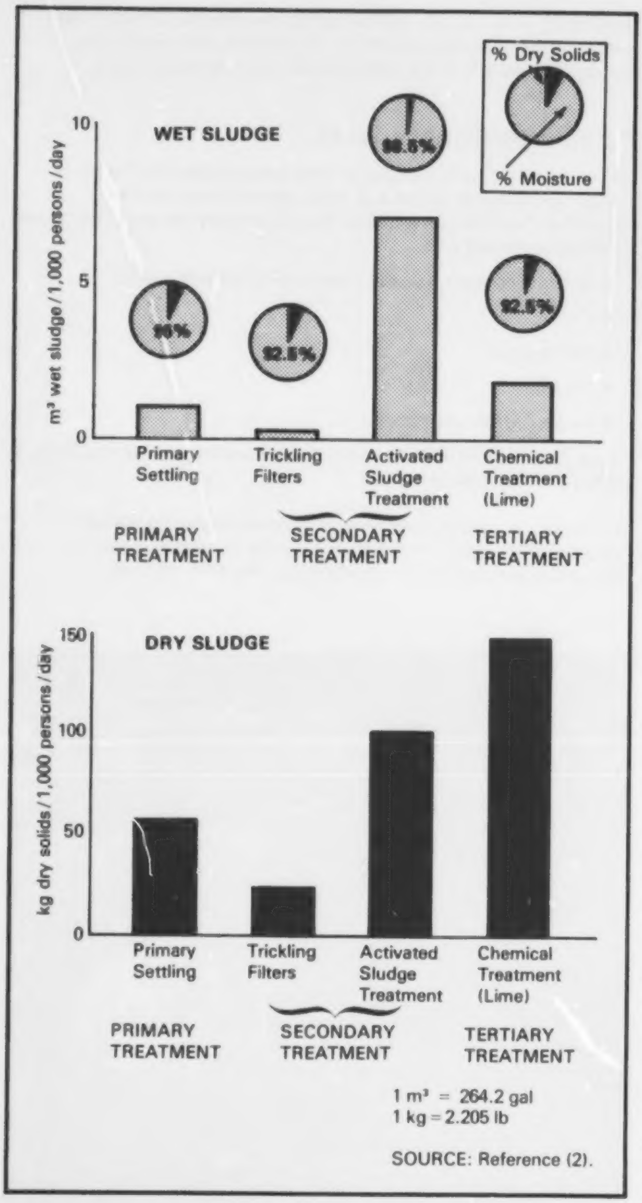
Treatment process and definition	Effect on sludge	Effect on use / disposal options
Pretreatment: Reduction in contaminant levels in industrial wastewater discharge.	Reduces levels of heavy metals and organics in industrial wastewater discharge, thereby lowering the concentration of these constituents in the sludge.	Increases the viability of land application, distribution and marketing, and ocean disposal. Reduces need for pollution control devices during incineration, and prevents problems with incinerator ash disposal.
Thickening: Low-force separation of water and solids by gravity or flotation.	Increases solids concentration of sludge by removing water, thereby lowering sludge volume.	Lowers sludge transportation costs for all options.
Digestion (Aerobic and Anaerobic): Biological stabilization of sludge through conversion of some of the organic matter to water, carbon dioxide, and methane.	Reduces the volatile and biodegradable organic content of sludge by converting it to soluble material and gas. Reduces pathogen levels and controls putrescibility.	Reduces sludge quantity. Preferred stabilization method prior to landfilling and land application. Reduces heat value for incineration, but anaerobic digestion produces recoverable methane.
Lime Stabilization: Stabilization of sludge through the addition of lime.	Raises sludge pH. Temporarily decreases biological activity. Reduces pathogen levels and controls putrescibility. Increases the dry solids mass of the sludge.	May be used prior to land application and landfilling. High pH of lime-stabilized sludge tends to immobilize heavy metals in sludge as long as the high pH levels are maintained.
Conditioning: Alteration of sludge properties to facilitate the separation of water from sludge. Conditioning can be performed in many ways, e.g., adding inorganic chemicals such as lime and ferric chloride; adding organic chemicals such as polymers; or briefly raising sludge temperature and pressure. Thermal conditioning also causes disinfection.	Improves sludge dewatering characteristics. Conditioning may increase the mass of dry solids to be handled and disposed of without increasing the organic content of the sludge.	Increases the amount of auxiliary fuel required in incineration if the amount of inert material in the sludge is increased.
Dewatering: High-force separation of water and solids.	Increases solids concentration of sludge by removing much of the entrained water, thereby lowering sludge volume. Some nitrogen and other soluble materials are removed with the water.	Reduces fuel costs for incineration. Reduces land requirements and bulking soil requirements for landfilling. Lowers sludge transportation costs for all options. Dewatering may be undesirable during land application in regions where the water itself is a valuable agricultural resource. Reduction of nitrogen levels may or may not be an advantage.
Composting: Aerobic process involving the biological stabilization of sludge in a windrow, in an aerated static pile, or in a vessel.	Lowers biological activity. Can destroy all pathogens. Degrades sludge to a humus-like material. Increases sludge mass due to addition of bulking agent.	Useful prior to land application and distribution and marketing. Often not appropriate for other use or disposal options due to cost.
Heat Drying: Application of heat to kill pathogens and eliminate most of the water content.	Disinfects sludge. Slightly lowers potential for odors and biological activity.	Generally used only prior to distribution and marketing.

2.2 Sludge Quantity

The amount of sludge that must be used or disposed of affects the economic and technical feasibility of the various use/disposal options. Two ways to look at sludge quantity are the *volume* of the wet sludge, which takes into account both the water content and solids content, and the *mass* of the dry sludge solids.

Sludge volume is expressed as liters (gallons) or cubic meters. Sludge mass is usually expressed in terms of weight, in units of dry metric tons (tons). Because the water content of sludge is large and highly variable, the mass of the dry sludge solids is often used to compare sludges with different proportions of water.

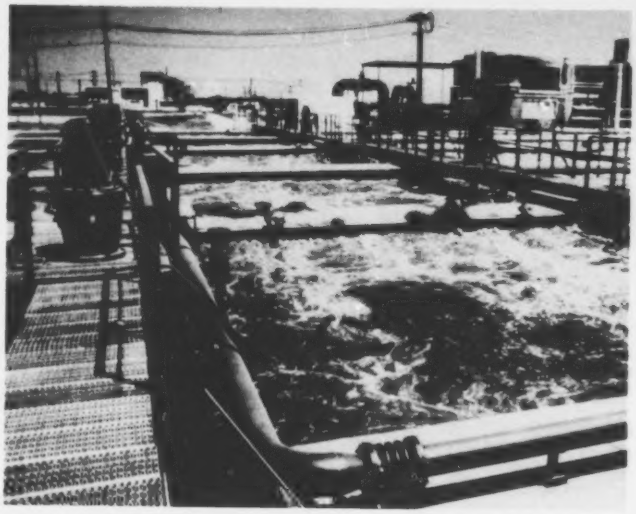
Key factors affecting sludge volume and mass are sources of the wastewater, wastewater treatment processes, and sludge treatment processes.



1 m³ = 264.2 gal
1 kg = 2.205 lb

SOURCE: Reference (2).

Figure 4. Typical Sludge Quantities Generated by Various Wastewater Treatment Processes



In activated sludge treatment, air is continuously injected into wastewater in aeration basins, which stimulates the growth of microorganisms to form an active mass of microbes called "activated sludge."

Wastewater Sources. Industrial contributions to wastewater influent streams can significantly increase the sludge quantity generated from a given amount of wastewater. Pretreatment provided by an industrial facility can greatly reduce sludge quantity by removing industrial contamination such as metals and organic chemicals.

Wastewater Treatment. Higher degrees of wastewater treatment generally increase sludge volume (Figure 4). For example, primary treatment typically produces 2,500 to 3,500 liters of sludge per million liters of wastewater treated. Biological secondary treatment produces an additional 15,000 to 20,000 liters per million liters of wastewater treated. Use of chemicals for phosphorus removal during tertiary treatment increases sludge volume another 10,000 liters per million liters treated.

Sludge Treatment. Some sludge treatment processes reduce sludge volume, some reduce sludge mass, and some actually increase sludge mass while improving other sludge characteristics. For example, dewatering processes reduce the amount of water in a sludge without significantly reducing the mass of solids; dewatering is thus purely a volume reduction process. Anaerobic digestion of sludge results in a loss of solid material through biodegradation; it is thus a mass reduction process. Although anaerobically digested sludges have less mass than the original raw sludges, they are equally as difficult to dewater, which means they tend to have a large volume. Inorganic chemical addition generally increases sludge mass while improving other characteristics for subsequent treatment, use, or disposal. For example, lime and ferric chloride are added to enhance a sludge's dewatering characteristics; in this case, sludge mass is increased although, at a subsequent dewatering step, sludge volume will be decreased. Composting, another type of sludge treatment, significantly increases mass through the addition of a bulking agent such as wood chips.

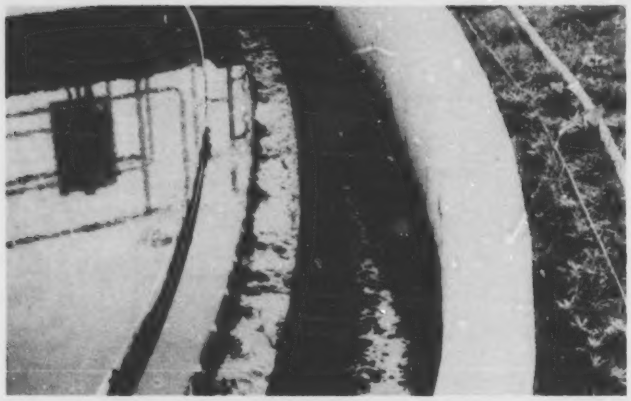
2.3 Sludge Constituents

The composition of a sludge can limit a municipality's choice of sludge use/disposal options or make certain options more appealing. The five constituents that are usually the most important in decision-making are:

- Organic content (usually measured as volatile solids).
- Nutrients.
- Pathogens.
- Metals.
- Toxic organic chemicals.

Figure 5 shows the importance of these constituents for the various sludge use/disposal options.

The major sources of toxic organic chemicals and metals are industrial discharges. Pretreatment can be an effective way to reduce the levels of these constituents. The EPA requires



Thickening—a sludge treatment process—reduces sludge volume by removing water from the wastewater solids, which sink and are collected from the center of the thickener. Shown here is the effluent weir of a circular gravity thickener.

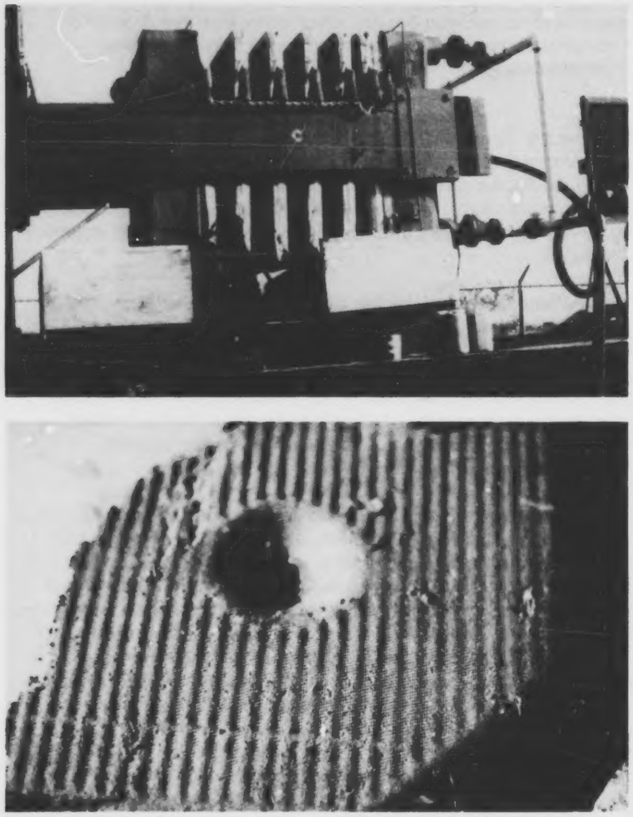


Plate and frame filter press and resulting sludge cake.

Sludge rolling off vacuum filters is checked for consistency.

wastewater treatment plants to implement industrial waste pretreatment programs to control the entry of potentially harmful wastes into the system. One of the primary methods for implementing industrial pretreatment is the sewer ordinance, which sets upper concentration limits for certain pollutants in wastewater.

2.3.1 Organic Content

Sludge organic content is most often expressed as the percent of the total solids (TS) that are volatile solids (VS). VS are organic compounds that are removed when the sludge is heated to 550°C (1,022°F) under oxidizing conditions. Most unstabilized sludges contain 75 to 85 percent VS on a dry weight basis. Organic content is an important determinant of thermal value (in incineration), potential for odor problems (in storage and land application), value as a soil conditioner (in land application), and potential for gas generation (in digesters).

	LAND APPLICATION	DISTRIBUTION AND MARKETING	LANDFILLING	INCINERATION	OCEAN DISPOSAL
Volatile Solids	◒	◒	◒	●	○
Nutrients	●	◒	◒	○	◒
Pathogens	●	●	○[a]	○	○[a]
Metals	●	●	◒	◒	◒
Toxic Organic Chemicals	◒	◒	◒	◒	◒

● Very Important
◒ Moderately Important
○ Not Important

[a] Based on current EPA information; however, assessment of potential effects continues.

Figure 5. Importance of Sludge Constituents to Sludge Use/Disposal Options

Table 3. Comparison of Nutrient Levels in Commercial Fertilizers and Wastewater Sludge

	Nutrients (%)		
	Nitrogen	Phosphorus	Potassium
Fertilizers for Typical Agricultural Use[a]	5	10	10
Typical Values for Stabilized Municipal Wastewater Sludge (3)	3.3	2.3	0.3

[a] Rates of application vary to reflect soil and crop needs, and the relative concentrations of nutrients in a fertilizer may range up to 82 percent nitrogen, up to 10 percent phosphorus, and up to 25 percent potassium.

2.3.2 Nutrients

Municipal sludges contain three essential nutrients for plant growth: nitrogen, phosphorus, and potassium. Typical sludge nutrient levels are considerably lower than those of commercial fertilizers (Table 3) although some sludges can contain more than 10 percent nitrogen and 8 percent phosphorus by dry weight. Potassium rarely occurs in sludge in significant concentrations.

A nutrient may be present in sludge in one of several chemical forms. For example, nitrogen may occur as organic nitrogen, ammonium and nitrate ions, and phosphorus may occur as phosphate and ortho-phosphate ions. Both the form and the concentration of nitrogen and phosphorus affect the fertilizer value of the sludge for land application. Reactions in the soil slowly convert most of the organic nitrogen forms into nitrate ions, which, like nitrates from fertilizers, is either used by plants or leached away. Nitrate is the most soluble form of nitrogen and therefore presents the most potential for contamination.

2.3.3 Pathogens

A significant proportion of the bacteria, viruses, protozoa, and eggs of parasitic worms in wastewater become concentrated in sludge during wastewater treatment. A small percentage of these organisms may be pathogenic (disease-causing). Pathogen abundance is difficult to measure directly, but pathogen reduction can be estimated from the reduction in concentration of indicator organisms (e.g., total fecal coliform bacteria). Pathogen levels can be substantially reduced by sludge treatment processes such as anaerobic digestion (Table 4). Note that the numbers of the parasite *Ascaris* are not reduced by this treatment method.

To preclude potential human exposure problems, EPA specifies two tiers of pathogen reduction prior to land application (see subsection 3.3.10). These are currently included in 39 state regulations, and EPA is seeking the nationwide incorporation of these controls into state regulations and enforcement efforts (5).

Table 4. Typical Pathogen Levels in Unstabilized and Anaerobically Digested Sludges

Pathogen	Typical concentration in unstabilized sludge (No. / 100 milliliters)	Typical concentration in anaerobically digested sludge (No. / 100 milliliters)
Virus	2,500 - 70,000	100 - 1,000
Fecal Coliform Bacteria[a]	1,000,000,000	30,000 - 6,000,000
Salmonella	8,000	3 - 62
Ascaris lumbricoides	200 - 1,000	0 - 1,000

[a] Although not pathogenic, they are frequently used as indicators.

SOURCE: Reference (4).

2.3.4 Metals

Sludges may contain varying amounts of heavy metals and inorganic ions such as boron, cadmium, chromium, copper, lead, nickel, mercury, silver, and zinc. At low concentrations in soil, some of these elements are essential micronutrients required by plants and animals, and are often added to inorganic commercial fertilizers and feed supplements. However, at high concentrations they may be toxic to humans, animals, and plants. The metals concentrations in a sludge are among the foremost considerations in land application because of their potential to damage crops and, in the case of cadmium, to enter the human food chain. Acceptable metal levels for land application have been a subject of considerable debate (6,7). Concentrations of metals are used as controls only in distribution and marketing. Table 5 lists ranges and medians for metals in sludges. Metals may also be a concern in landfilling, if conditions are acidic and promote leaching of metals, and in incineration, if improper design or operating procedures result in the release of metals into the atmosphere.

Table 5. Metals in Sludge

Metal	Dry sludge (mg / kg)	
	Range[a]	Median[a]
Zinc	101 - 49,000	1,700
Lead	13 - 26,000	500
Copper	84 - 17,000	800
Nickel	2 - 5,300	80
Cadmium	1 - 3,410	10
Mercury	0.6 - 56	6
Arsenic	1.1 - 230	10
Cobalt	11.3 - 2,490	30
Chromium	10 - 99,000	500
Iron	1,000 - 154,000	17,000
Manganese	32 - 9,870	260
Molybdenum	0.1 - 214	4
Tin	2.6 - 329	14
Selenium	1.7 - 17.2	5

[a] Reference (6).

Concentrations of metals are primarily a function of the type and amount of industrial waste that is discharged into the municipal wastewater treatment system. Industrial pretreatment and source control programs can control or reduce the metals content of sludge. Good management practices in land application, landfilling, and incineration may minimize or eliminate the potential for adverse effects.

Regulations under the Resource Conservation and Recovery Act (RCRA) (44 FR 53438) identify listed hazardous wastes and hazardous waste characteristics. Municipal wastewater sludge is neither excluded nor specifically listed as hazardous waste. However, sludges from highly industrialized areas may need to be evaluated for the characteristics that designate hazardous waste. The test most appropriate to municipal wastewater sludge is the Extraction Procedure (EP) toxicity test. States administering the hazardous waste program may have additional criteria for identifying and handling hazardous wastes. If a sludge fails the EP test (i.e., demonstrates metal toxicity), it must be handled as a hazardous waste according to the requirements of RCRA. Nonhazardous sludges are subject to RCRA solid waste regulations.

2.3.5 Toxic Organic Chemicals

Sludges can contain synthetic organic chemicals from industrial wastes, household chemicals, and pesticides. Most sludges contain low levels of these substances and do not pose a significant human health or environmental threat. Exposure to these chemicals is a concern in land application, distribution and marketing, and landfilling, but adherence to good practices as described in Chapters 3, 4, and 5 will prevent detrimental effects.

2.4 Sludge Characteristics

Sludge is usually treated with the aim of improving its characteristics for ultimate use/disposal. The importance of sludge characteristics for each sludge use/disposal option is illustrated in Figure 6. Typical goals of sludge treatment include reducing water content, reducing sludge mass, controlling odors, and destroying pathogens. Major sludge treatment processes and their benefits are described in Table 2.

Water Content. Sludges typically contain 93 to 99.5 percent water. The concentration varies significantly depending on the type of sludge. Sludge water content affects:

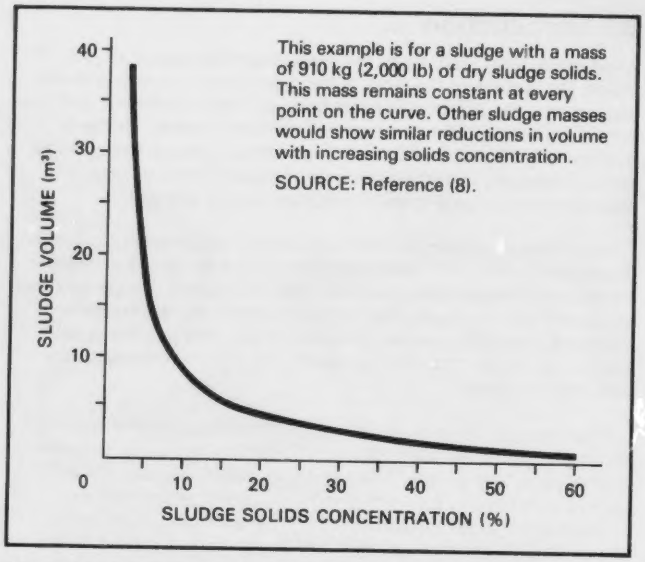
- Size of sludge treatment and disposal facilities.
- Sludge transportation costs.
- Type of land application equipment used.
- Amount of auxiliary fuel needed to evaporate water during incineration.

- Size and lifespan of a sludge landfill.
- Leachate formation in landfilling.

Sludge water content is inversely related to sludge solids content, which is usually expressed as percent TS. The higher the percent solids, the lower the water content. Treatment processes such as thickening, conditioning, dewatering, composting, and drying can lower sludge water content and thus raise the percent solids. Doubling the solids content of a sludge (e.g., raising it from 5 to 10 percent TS) halves the volume of sludge that must be used or disposed of (see Figure 7).

Degree of Stabilization. Stabilization refers to a number of processes that reduce the potential for odor. Stabilization processes also reduce pathogen levels and, usually, volatile solids content. Major methods of stabilization include anaerobic digestion, aerobic digestion, lime stabilization, and composting. Anaerobic digestion is the most common method of sludge stabilization, and generally biodegrades about 50 percent of the volatile solids in a sludge. Because much of the organic matter has already been eliminated, stabilized sludges tend not to have odor problems. Low pathogen levels and low odor potential are often desirable and sometimes required prior to ultimate use/disposal (for example, in land application).

pH. The acidity of a sludge (measured by pH) affects the availability of heavy metals, the pathogen content of the sludge, and the corrosivity of the sludge. High pH (greater than 11) sludges destroy many bacteria and, in conjunction with soils of neutral or high pH, can inhibit movement of heavy metals through soils and uptake of heavy metals by plants. Conversely, low pH (less than about 6.5) sludges promote leaching of heavy metals and promote greater crop uptake of metals. Leaching of heavy metals can occur at landfills because acid conditions often prevail. Thus, pH affects the suitability of sludge for land application, distribution and marketing, and landfilling. Low pH sludges are also corrosive, and must be treated to prevent equipment damage during incineration.



This example is for a sludge with a mass of 910 kg (2,000 lb) of dry sludge solids. This mass remains constant at every point on the curve. Other sludge masses would show similar reductions in volume with increasing solids concentration.

SOURCE: Reference (8).

Figure 7. Change in Sludge Volume with Increase in Sludge Solids Concentration

	LAND APPLICATION	DISTRIBUTION AND MARKETING	LANDFILLING	INCINERATION	OCEAN DISPOSAL
Water Content	◒	●	●	●	◒
Degree of Stabilization	●	●	◒	●[a]	◒
pH	●	●	●	◒[b]	○

● Very Important
◒ Moderately Important
○ Not Important

[a] Biological stabilization may reduce the fuel value of sludge by as much as one half.

[b] Low pH is corrosive.

Figure 6. Importance of Sludge Characteristics to Sludge Use/Disposal Options

3. Land Application

3.1 Introduction

Land application, defined as the spreading of sludge on or just below the surface of the land, is the most widely employed sludge use option. The sludge can serve both as a soil conditioner and as a partial replacement for commercial fertilizers. Usually, sludge is applied to land in one of four settings: on agricultural lands, forest lands, drastically disturbed lands (land reclamation), or land dedicated to sludge disposal (dedicated land disposal).

Three of the four types of land application—agricultural application, forest application, and land reclamation—use sludge as a valuable resource to improve the characteristics of the land. Sludge acts as a soil conditioner by facilitating nutrient uptake, increasing water retention, permitting easier root penetration, and improving soil texture (which in turn reduces runoff and erosion and makes the soil easier to work).

Sludge also serves as a partial replacement for expensive chemical fertilizers. The major constituents of chemical fertilizers—nitrogen, phosphorus, and even small amounts of potassium (see Table 3)—as well as many trace elements required by plants are found in wastewater sludge, though usually not in optimal proportions. Based on 1983 fertilizer prices in the South-Central United States a metric ton of dry sludge solids would contain approximately $9.08 worth of nitrogen, $28.33 worth of phosphorus, and $0.66 worth of potassium.

Concurrent with improving soil productivity, land application also functions as a sludge treatment system. Sunlight, soil microorganisms, and desiccation help to destroy pathogens and many toxic organic substances in the sludge. Heavy metals and, to some extent, nutrients in sludge are trapped by soil as a result of soil's various physical and chemical characteristics. Nutrients, which can cause eutrophication and other problems if released into surface waters, are instead largely converted into useful biomass such as crops or wood. However, the capacity of the land to treat sludge constituents is finite, and land application systems must be designed and managed to work within the assimilative capacity of the land and the crops grown on it.

Municipalities in every part of the country are successfully using land application and have been doing so for many decades. Land application has been used successfully by both small towns and large cities. Currently about 25 percent of the nation's sludge is land applied.

This breadth of experience has shown land application to be a safe and effective wastewater sludge use option. In particular, research during the last 10 years has produced new knowledge which allows the full benefits of sludge application to be achieved with negligible impacts (9).

Many states have begun to promote land application as the sludge use/disposal option of choice. For example, Pennsylvania now requires the application of wastewater sludge to be considered as one alternative in any disturbed land reclamation plan, and New Jersey is promoting the reduction of toxic organic chemical and metal concentrations in all municipal sludges, so that they can be recycled by land application.

3.2 Process and Performance

Three aspects of a land application system greatly affect its success: site characteristics, application rates, and the sludge application system. Together these three conditions determine both the potential for environmental or health problems and the economics of sludge application.

All three conditions are intimately intertwined. Site selection is influenced by the amount of land required to apply all the sludge. The amount of land needed depends on the sludge loading rate, which in turn depends on the sludge's characteristics, on which application alternative (e.g., forest land application) is to be used, and on the sludge application method (e.g., injection of liquid sludge). Site characteristics may also influence sludge application rates.

3.2.1 Site Characteristics

Site characteristics greatly affect the potential environmental impacts of sludge application; consequently, site selection is an important aspect of all land application systems. Factors of concern include depth to ground water, distance to surface waters, slope of the site, soil permeability, soil pH, soil cation exchange capacity, and depth and type of bedrock.

The greater the *depth to ground water* and *distance to surface waters*, the less potential for contamination exists. Guidance on appropriate depths and distances can be found in reference (9).

The *slope of a site* affects the rate and amount of runoff from the site. For agricultural application, slopes of less than 6 percent are generally considered acceptable, and slopes of less than 3 percent are ideal. Slopes of up to 15 percent can be managed safely, but on steeper sites high runoff velocities may carry sludge constituents and soil into nearby lakes or streams if runoff controls are not installed. Sites with extremely low *soil permeability* should not be used for land application as ponds may form during high rainfall.

Soil characteristics, particularly pH and cation exchange capacity, affect the potential for contamination of the food chain by heavy metals. High *soil pH* immobilizes most metals and reduces their absorption by plants. For agricultural application, the pH of the soil must be at or above 6.5 at the time of sludge application (see subsection 3.3.10). This requirement has been questioned by researchers who note that acceptable programs can be conducted at lower, naturally occurring pH levels, and that other controls such as crop monitoring can be used. In some situations, such as application to forest lands where soils are naturally acid, it may be impractical to raise the pH to 6.5. However, since the products of forest lands are usually not major components of the human diet, heavy metals in forest soils are of concern only as they affect the health of forest plants and animals and can contaminate aquifers and surface waters.

The *cation exchange capacity*, which is an indirect measure of the soil's ability to capture positive ions (the form in which most metals are found in the soil), can also be important in planning land application systems. Soils with a high cation exchange capacity can generally receive higher levels of metals than soils with a low cation exchange capacity. Other soil characteristics, such as *clay-mineral content* and *organic matter content*, can greatly influence metal retention.

Other site characteristics of importance are the *proximity of the site to social and cultural facilities* such as homes, schools, and other public buildings. A strip of land between the sludge application site and such facilities may be desirable to enhance public acceptance of the sludge application program. Such a buffer zone may also be desirable on unfenced sites to reduce the chances that children, adults, or pets will directly contact the sludge.

Unless special precautions are taken, application sites should not be located in areas underlain by fractured *bedrock* or containing sinkholes, as these types of geologic formations may provide a route for rapid transport of pollutants to nearby aquifers.

3.2.2 Application Rates

As with commercial fertilizers, the primary means of managing land application is by controlling the application rate to optimally disperse sludge constituents. The two constituents that are usually most important to control are nitrogen and cadmium; however, several other sludge constituents may also govern application rates. Rates of application are calculated based on crop needs, permissible sludge constituent concentrations (based on health and environmental effects), and soil characteristics. Application rates are designed so that the limiting constituent is applied in appropriate quantities.

Limiting constituents vary with how the sludge will be used. In agricultural application, crop nutrient needs and potential contamination and phytotoxicity from heavy metals are major concerns; therefore, nitrogen, cadmium, and/or another heavy metal often limit application levels. In dedicated land disposal, where the crops grown are typically not food chain crops, metals are usually of much less concern.

The application rate is the primary factor to be considered in determining the amount of land required—the higher the application rate the less land needed to handle sludge production. In dedicated land disposal, sludge is applied at high rates to a small piece of land under intensive management to preclude detrimental environmental effects. In agricultural application, the sludge is applied to a larger land area at much lower rates, which reduces the danger of environmental degradation and, consequently, the need for intensive management. In forest land application and land reclamation, large quantities of sludge are applied at infrequent intervals. Cumulative application rates are usually as low as those for agricultural application.

3.2.3 Application of the Sludge

Both liquid and dewatered sludge can be applied beneficially to land. The sludge can be spread onto the surface or incorporated into the soil. Each of these choices has advantages and disadvantages.

Thickening or dewatering processes reduce both the water content and the soluble nitrogen content of sludge. Because nitrogen usually limits application rates, reducing nitrogen levels may be an advantage if only a small area of land is available, since greater quantities of wastewater solids can be applied without exceeding the nitrogen loading capacity of the soil. On the other hand, a high nitrogen content in sludge may be of value for promoting plant growth.

The decrease in water content may be beneficial, since it reduces handling costs, including those for transportation. Generally the reduction in transportation costs is more important for large municipalities, which often must transport the sludge a greater distance to reach a suitable site. Many small communities will not need to invest in dewatering equipment.

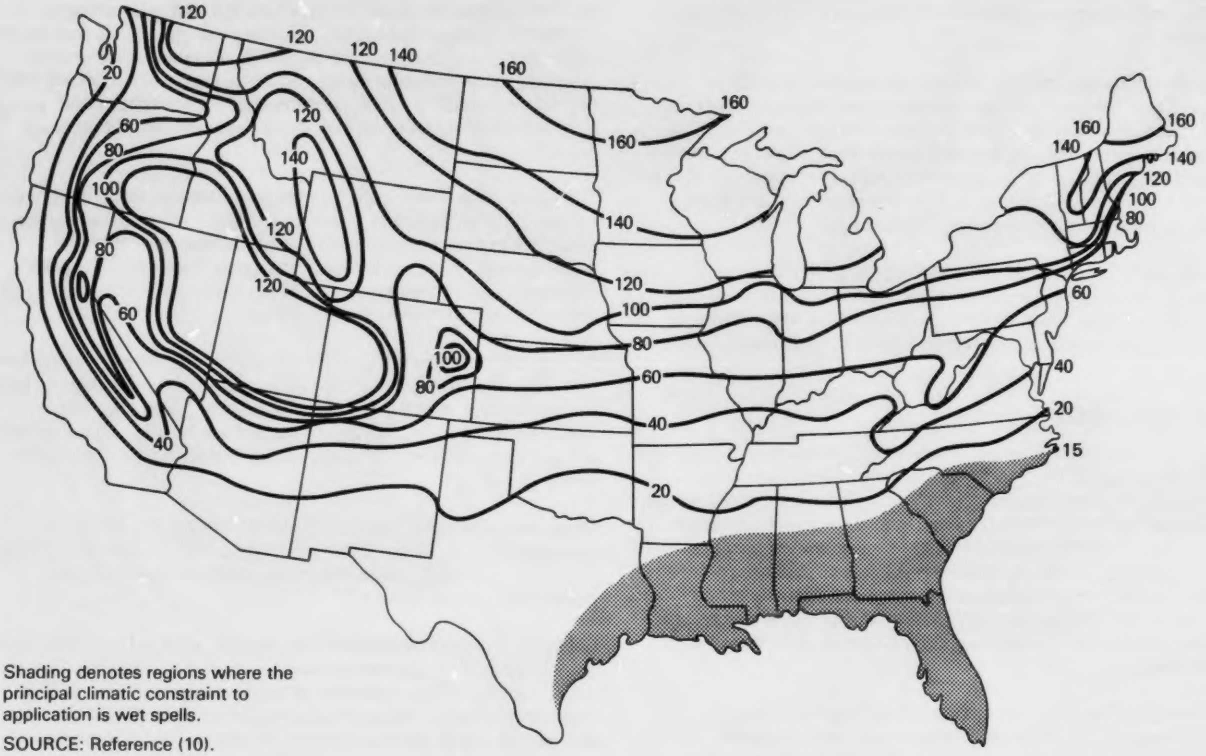
Dewatered sludge is ordinarily surface applied. Dewatered sludge is first spread on the soil surface and subsequently incorporated into the upper layer of soil by plowing or discing. With specially designed equipment, dewatered sludge can be injected below the soil surface, provided the sludge solids content does not exceed about 20 percent.

Sludges may also be applied to land in composted, air-dried, or heat-dried forms. These dried forms are easier to store and, in the case of composted sludge, are more stabilized than the liquid or dewatered sludges.

Liquid sludge may be injected into the soil, sprayed or spread over the soil surface, or applied by ridge-and-furrow irrigation. The subsurface methods—injection of liquid sludge and incorporation of dewatered sludge—reduce the potential for contact between the sludge and crops, grazing animals, or people, and reduce the potential for sludge erosion. In addition, subsurface application can eliminate significant odors. Surface application allows ammonia and volatile toxic organic chemicals to disperse into the atmosphere. Surface-applied sludge is also exposed to sunlight and air, which helps destroy toxic organic chemicals and pathogens.

The choice of application method may be limited by locally specific factors. For example, ridge-and-furrow irrigation requires flat land that is carefully graded.

A key factor affecting the scheduling of sludge application is climate. Sludge application to saturated soils or to frozen or snow-covered ground greatly increases sludge runoff and erosion and should be avoided. Consequently, municipalities must have sufficient capacity to store sludge during unfavorable conditions. Figure 8 shows an estimate of the number of days of storage required in various parts of the country based on climatic factors alone. For some crops that make the application site inaccessible (e.g., corn), sludge storage is required. Additional storage may be required during the crop harvesting period, to provide system backup, or to equalize application rates over the course of the year.



Shading denotes regions where the principal climatic constraint to application is wet spells.

SOURCE: Reference (10).

Figure 8. Estimated Number of Days that Sludge Storage is Required Based Solely on Climatic Factors (Temperature, Precipitation, and Snowcover)

3.2.4 Agricultural Use

Agricultural use of sludge is the most widely used of all land application methods. Sludges may be applied to a wide range of crops, including grains, animal feeds, and nonfood crops. Municipalities should retain enough control over the process to ensure that safe practices are followed in order to preclude adverse effects on the food chain.

Agricultural application does not usually require the municipality to purchase any land. The responsibilities of the farmer and the municipality can be laid out in a contract, which may cover liability for any damages, whether the farmer will pay for the sludge or be paid to take it, when the sludge may be applied, how much sludge can be applied, and under what conditions sludge application can be terminated by one of the parties to the contract. Figure 9 shows a sample contract. This was developed as part of an EPA demonstration project with the Ohio Farm Bureau. The contract can be adapted for local use by changing the costs, the application rate, and other terms.

Agricultural application is often extremely economical. In most cases the farmland to which the sludge is applied is kept on the tax rolls, in contrast to incineration, landfilling, and dedicated land disposal, where the municipality usually owns the land. Farmers participating in land application may save money by reducing their dependence on expensive chemical fertilizers. In some regions of the country the water added to the soil during sludge application is also a valuable resource.

Soil Conservation Service officials and the county agricultural extension agent are usually a municipality's prime contact with local farmers. These officials are familiar with the opportunities presented by sludge use and the operational needs and concerns of local farmers, and can assist in designing and implementing a land application program. Local farm bureaus may also assist. Such contacts are usually essential to generate farmer support for an agricultural application program.

CONTRACT

THIS CONTRACT, made this ____ day of ______________, 19____, by and between ______________________________, hereinafter referred to as Owner, and ______________________________, hereinafter referred to as City, witnesseth that,

WHEREAS, Owner is the owner of a parcel of agricultural real property located in (PARCEL NO.), (TOWNSHIP), (COUNTY), Ohio, which can be reached as follows: ______________________________, and

WHEREAS, City operates a waste treatment or disposal plant which after processing produces a product known as sewage sludge, and

WHEREAS, Owner will allow sewage sludge from City to be placed on the above-mentioned real property only on the terms set out below,

NOW THEREFORE, Owner and City mutually agree as follows:

1. The "Ohio Guide for Land Application of Sewage Sludge," Bulletin 598 of the Cooperative Extension Service of the Ohio State University, as revised in May, 1976, shall be used as a guideline for responsible management practices. Hereinafter Bulletin 598 will be referred to as "The 1976 Guide."

2. The City will deliver sewage sludge to the above-mentioned property of Owner and will properly spread or otherwise deposit said sewage sludge on said property without charge to the Owner. City shall be responsible for all equipment used to deliver and spread such sewage sludge.

3. The Owner and the City will mutually agree on the specific portion of said property which is to receive sludge. In the absence of unusual factors, they will abide by the site election criteria of the 1976 Guide.

4. The Owner or his representative may decline to receive sludge on said property when, in Owners's or his representative's judgement, the sludge application equipment would damage the soil structure because of excessive soil moisture at the disposal site. When possible, the Owner will give the City notice of poor field conditions 24 hours prior to the appointed application time. However, the City does realize that this is not always possible and that there will be some days when untimely excessive rainfall will require termination of spreading activities at a moment's notice on a given field.

5. The Owner will notify City in writing of the dates between which City may deliver and spread sewage sludge. The City may deliver said sewage sludge only during the period thus described. The Owner will make himself or his representative available to City or its employees during such period to ensure said sewage sludge is deposited on the proper location on said property.

6. Owner shall specify the access to be used by the City when sewage sludge is applied to a specific portion of said property. The Owner shall provide and maintain an access for use by the City without charge to the City, and the City shall not be liable for any damages thereto, except damage caused by City's negligence.

7. Using the criteria of the 1976 guide, the Owner and the City have mutually agreed on the rates and amounts per acre said sewage sludge is to be applied during the Contract period. For the term of this Contract, Owner will adhere to mutually agreed upon application rates listed in Attachment A which is included as a part of this Contract.

8. The City shall properly analyze its sewage sludge on a monthly basis for the total nitrogen, ammonia and nitrate nitrogen, phosphate, potassium, lead, zinc, nickel, copper, and cadmium content. The results of such analysis will be provided to the Owner or his representative upon request without charge before sludge is applied to said property.

9. City shall keep and maintain records of the following items, and shall make such records available to Owner or his representative upon request:

(a) All analyses of the composition of sewage sludge produced by the City.
(b) All reports concerning the operation or production of sewage sludge by the City.
(c) All applications to agricultural land of sewage sludge produced by City including dates of application, amounts applied, specified rates of application, specific parcels of land upon which sewage sludge has been applied.
(d) All required governmental permits or approvals for the application of sewage sludge on agricultural land.

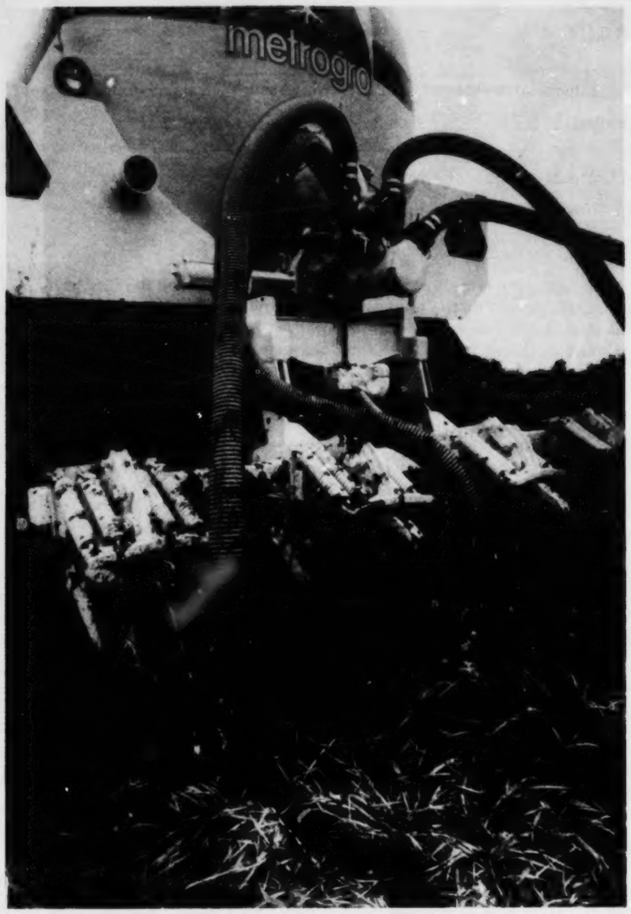
10. City will deliver and apply sludge which is well stabilized and which does not present a severe odor nuisance to Owner or other rural residents who live in the vicinity of the sludge disposal site. The Owner may refuse to accept any sludge which is exceptionally odorous.

11. The Contract shall continue in effect for a period of three years following the date first above written. The Parties hereto may renew this Contract in writing. Either party may cancel this Contract by giving written notice to the other party of the intention to do so. Cancellation will be effective five days after receipt of such notice. Such notices shall be delivered personally or by certified mail to the address(es) listed at the end of this Contract.

OWNER:
____
____
Address: ______________________________
____
____
____

CITY:
____
By ______________________________
Title ______________________________
By ______________________________
Title ______________________________
Address: ______________________________
____

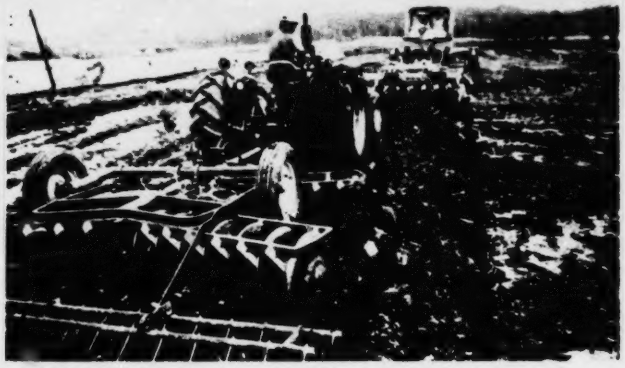
Figure 9. Sample Contract Between a Farmer and a Municipality



Agricultural application and incorporation of sludge.

a. Subsurface injection of sludge.

Agricultural application rates generally range from 2 to 70 dry metric tons per hectare per year (mt/ha/yr). This is equivalent to a rate of 1 to 30 dry tons per acre per year (tons/ac/yr). A typical rate would be 15 dry mt/ha/yr (6.7 tons/ac/yr). Application rates are usually limited by either the nitrogen needs of the crop grown or by the annual or cumulative metals addition to the soil. Less frequently, application rates are limited by the phosphorus needs of the crop. Phosphorus-based rates are generally lower than metal- or nitrogen-based rates due to the relatively low phosphorus needs of most crops.



b. Incorporation of sludge into the soil surface by discing.

c. Surface application of liquid sludge by truck. Balloon tires prevent soil compaction in wet conditions.

d. Surface application of liquid sludge by tractor.

The heavy metal contact of sludge has been extensively studied as a potential source of human exposure through the food chain. Research has shown that several factors act as barriers to human exposure to heavy metals in land-applied sludge. Because metals have low solubility, uptake by plants is minimal. Metals that are taken up tend to remain in the roots, preventing buildup of toxic metal concentrations in edible plant parts. In addition, most metals visibly damage crops at concentrations far lower than those that affect human health (14). However, cadmium does not have phytotoxic effects and, for this reason, is subject to strong regulatory controls.

A 1981 joint statement by the U.S. Environmental Protection Agency (EPA), U.S. Food and Drug Administration, and U.S. Department of Agriculture recommended that only "good" sludges [i.e., those containing less than 25 milligrams per kilogram (mg/kg) of cadmium, 10 mg/kg of polychlorinated biphenyls (PCBs), and less than 1,000 mg/kg of lead on a dry weight basis] be used for growing fruits and vegetables (13).

References (9,11,12,13) should be consulted for further information on agricultural application. Many states have also published documents containing guidance for the particular climates, soils, and cropping patterns found within their boundaries, as well as detailed regulations affecting agricultural use. Federal regulations on agricultural application are discussed in subsection 3.3.10.

3.2.5 Forest Land Application

Sludge application can greatly improve forest productivity. Studies at the University of Washington on the use of sludge as a fertilizer in silviculture showed height increases of up to 1,190 percent and diameter increases of up to 1,250 percent compared to controls in certain tree species.

Forest soils are in many ways well suited to sludge application. They have high rates of infiltration (which reduce runoff and ponding), large amounts of organic material (which immobilize metals from the sludge), and perennial root systems (which allow year-round application in mild climates). Although forest soils are frequently quite acid, research at the University of Washington has found no problems with metal leaching following sludge application.

One major advantage of forest application over agricultural application is that forest products (e.g., wild edible berries, mushrooms, game, and nuts) are an insignificant part of the human food chain. The primary environmental and public health concern associated with forest application is therefore pollution of water supplies. In many areas, particularly in the western states, forest lands form crucial watersheds and groundwater recharge areas. Contamination of water supplies by nitrates can be prevented by limiting sludge application rates according to the nitrogen needs of the trees, which usually is equivalent to a rate of 10 to 220 mt/ha (4 to 100 tons/ac) in a single application every 3 to 5 years. A typical application rate would be 40 mt/ha every 5 years (18 tons/ac every 5 years), which is equivalent to an average yearly

Municipal wastewater sludge is being incorporated into a slope as one of the first steps in a forest application program. The site was then planted with Douglas fir.

Once the seedlings have been planted, sludge must be sprayed onto the land in order not to disturb their growth. Here sludge is being sprayed in early spring while the trees are dormant in order to avoid damaging new foliage.

Douglas fir seedling about 6 weeks after over-the-canopy sludge application, with grasses reappearing.

Young Douglas fir trees about 10 weeks after over-the-canopy sludge application. Rain has washed away much of the sludge from older foliage, and new foliage is emerging.

Comparable branches from control Douglas fir tree (no sludge application) on the left, and sludge-treated tree on the right. Note the differences in foliage cover and branch size (white ruler is 12 in long).

application rate slightly less than that for agricultural application (4,11).

As in any fertilizer use, residual nutrient loadings from the previous sludge and fertilizer applications must be considered. Trees take up nitrogen and other nutrients and incorporate them into leaves, branches, and trunks. Unless the trees are cut for lumber or pulpwood, the leaves and eventually the trees themselves fall and decay, releasing the nutrients into the soil. Thus, successive sludge applications on forest lands should be controlled to provide only the level of nutrients that can be used beneficially.

Currently, few municipalities are using forest application as their principal means of sludge use/disposal, and guidance on this option is limited. As in agricultural application, the Soil Conservation Service and county extension agents may be able to help with program design and implementation.

Forest lands are often extremely rough, so special application vehicles may be required unless the land contains an adequate road system. Seattle, Washington, has purchased such vehicles for its forest application program. These vehicles have four-wheel drive, are hinged in the middle, can traverse 25 percent slopes, and have flotation tires for use on wet soils. Each vehicle cost about $175,000 in early 1983.

3.2.6 Land Reclamation

Sludge can help return barren land to productivity. According to preliminary results of a 1982 survey by the U.S. Soil Conservation Service, 1.6 million ha (4 million ac) of land disturbed by mines, quarries, or sand and gravel pits remains unreclaimed (15). Unreclaimed lands are often barren and frequently harmful to the surrounding environment. They may have such problems as acid runoff, high erosion rates, low nutrient levels, and toxic levels of trace metals. Application of wastewater sludge can improve all these characteristics.

Spraying sludge under the canopy of an older Douglas fir stand. The cannon-mounted sludge application vehicle can pump sludge 30 to 50 m (100 to 160 ft).

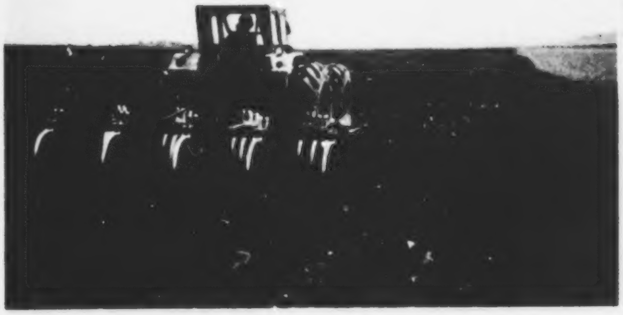
The amount of sludge applied at one time during land reclamation can be relatively large, ranging from 7 to 450 dry mt/ha (3 to 200 ton/ac). This is necessary to ensure that sufficient organic matter and nutrients are introduced into the soil to support vegetation until a self-sustaining ecosystem is established. A typical one-time application would be 112 mt/ha (50 ton/ac). Usually the sludge is applied and incorporated into the soil, the land is reseeded, and no further sludge is applied. Depending on site topography and sludge treatment prior to application, some contamination of ground and surface waters might occur immediately following sludge application, particularly by nitrate nitrogen. Similar problems occur during land reclamation with chemical fertilizers, and such effects are usually negligible compared to the environmental problems present prior to reclamation. Since sludge is usually applied only once, the cumulative amount of metals and persistent organic chemicals applied during land reclamation may be less than the cumulative amount applied during agricultural application or forest land application, assuming a 20-year lifetime for forest and agricultural sites.

Good practices reduce the potential for adverse effects from sludge application during land reclamation, and also maximize the likelihood of success. For example, the type of sludge applied may be important. Research has suggested that large applications of composted sludge minimize the quantity of nitrogen leached to ground water or lost to surface waters (since the nitrogen in composted sludge has low solubility), while providing sufficient organic matter and nutrients to sustain vegetative growth for at least 10 years (16). Large applications of digested sludge, on the other hand, provide sufficient organic matter, but pose a greater threat to water supplies due to the presence of large quantities of soluble nitrogen in the sludge which can be readily oxidized to the nitrate form and enter the ground water. Smaller applications of digested sludge may provide insufficient organic matter to restore soil fertility (16). The benefits of applying composted sludge must be weighed against the cost of composting, and against the lower availability of nitrogen during the critical early stages of vegetation growth.

Use of sludge to reclaim strip-mined land.

a. An active strip mine.

b. Application of sludge to strip-mined land.



c. Incorporation of the sludge.

Other important aspects of good practice include prompt revegetation to prevent erosion, and site preparation prior to sludge application to improve infiltration rates and reduce site slopes, thereby further reducing the potential for runoff and erosion (11,16).

Categories of land appropriate for reclamation efforts include surface mine spoils, mine tailings, borrow pits, quarries, cleared forests, dredge spoils, fly ash, completed land fills, and construction sites. These sites are often extremely difficult to revegetate due to the poor characteristics of the soil. Historically, land reclamation with sludge has been very successful. A recent summary reported that of 20 projects using sludge for land reclamation all but one were successful in a short period of time (16). The one failure was apparently due to a severe drought and, with irrigation, this program later achieved success.

d. Reclaimed land after sludge application. Vegetation growth can reach this level in as little as 5 months.

A municipality contemplating sludge-based land reclamation should be certain that there is sufficient land requiring such treatment within economical transport distance. The site management considerations in land reclamation are frequently more complex than in other land application schemes, due to the drastic alteration in soil characteristics desired and the need to satisfy regulations pertaining both to sludge use and mine land reclamation.

3.2.7 Dedicated Land Disposal

In dedicated land disposal relatively large quantities of sludge are applied to a land area for many years. The objective of this practice is to employ the land as a treatment system by using soil to bind metals, and soil microorganisms, sunlight, and oxidation to destroy the organic matter in the sludge. Often, no attempt is made to productively use the sludge nutrients.

Dedicated land disposal allows a municipality considerable control over the ultimate fate of the sludge, at the cost of more intensive management. Because the application area usually is owned or leased by the municipality, there is no need to convince farmers, lumber companies, or mining companies to participate in the program. The dedicated land disposal site may be located on the wastewater treatment plant grounds, thus reducing transportation costs.

Application rates range from 220 to 900 dry mt/ha/yr (100 to 400 tons/ac/yr), approximately 20 times those of agricultural lands. Dedicated sites where crops are grown will have application rates toward the lower end of this range.

To prevent environmental degradation, Federal regulations require that the sites not contaminate any ground or surface waters outside site boundaries. Necessary precautions at dedicated sites may include physical barriers to control runoff and leaching, careful monitoring for contamination of ground and surface waters, and remedial efforts in the event of contamination. Often leachate and runoff water must be captured and treated prior to release.

After completion of a dedicated land disposal program, the soil should be analyzed for heavy metals levels. Should high levels of heavy metals have built up, it may be necessary to either prohibit future production of food chain crops on the land; manage the site permanently as a park or other facility that will preclude crop production; cover the site; or remove the top layer of soil. Any of these options will increase the cost of the operation, either by requiring expenditures after closure, or by reducing the value of the land for resale. However, since dedicated land disposal requires relatively little land, and savings in transportation costs can be substantial, this option may result in overall economic savings compared to other land application systems.

While it is not required, vegetation should be grown on the disposal site. Because of the potential for high rates of metal uptake associated with high application rates, the plants grown should not be used for human consumption. Suitable crops can include sod, pulpwood, and animal feeds. Vegetation will help remove nutrients and heavy metals from the soil, and thereby reduce the groundwater contamination potential presented by the high application rates. Plants will also increase soil aeration, promote good drainage, and reduce odors. Vegetation on the site improves aesthetics and working conditions at the site. In addition, crops will reduce erosion and runoff from the site and, through transpiration, will reduce the amount of water that must be captured and treated.

3.3 Key Parameters

3.3.1 Treatment Requirements

Federal regulations require *stabilization* of sludge prior to land application in order to reduce odors and lower pathogen levels. Details of sludge stabilization methods are provided in Federal regulations and in reference (4).

Thickening or *dewatering* processes are also often considered during the design of a land application system. Decreasing the volume of sludge to be handled generally reduces transportation costs. On the other hand, dewatering beyond 8 to 10 percent solids content rules out pipelines, spray application, and irrigation as application methods. Dewatering also reduces the nitrogen content of the sludge because much of the soluble nitrogen is removed with the water. Thus the need for dewatering depends on the objectives of the particular application program.

3.3.2 Community Size

Land application is practiced successfully by communities of all sizes.

3.3.3 Land Requirements

The *amount of land required* varies with sludge quality, climate, the crops grown, and site characteristics.

Site characteristics influence the potential for adverse environmental and public health effects from a sludge application program, public acceptance of the program, and the cost of its operation. Evaluation of site characteristics is detailed in reference (11).

Sludge application must also be compatible with *current and future land uses*. For example, the crops to be grown on sludge-amended soil must be compatible with traditional cropping patterns used in the area. Conservative application rates should be used when future land use is difficult to predict. For example, on agriculture lands that move in and out of production as demand rises and falls, and on forest lands that may ultimately be developed for agriculture, some states limit cumulative heavy metals to the same levels used for agricultural lands that are in continual production.

3.3.4 Storage Requirements

All land application programs require some storage facilities. The volume of storage needed may range from the equivalent of 15 days' production in hot, arid climates where the weather rarely prevents sludge application, to 160 days in cold, damp climates where sludge application may be impossible over much of the year (see subsection 3.2.3). Storage should also be provided in the event of equipment failures and other service disruptions.

3.3.5 Good Practices

No factor is more crucial to successful, economical, and safe land application than good practice in system management. The aspects of good practice are myriad, and beyond the scope of this document. A few have been described in Sections 3.1 and 3.2. More detailed guidance on appropriate practice should be sought from EPA and state agencies as plans are made to implement a land application program.

One important factor in good practice is *runoff and erosion control*. Even on relatively level sites, good soil conservation practices must be followed to prevent sludge constituents from entering surface waters. This is particularly important in agricultural application, where new crops with new root structures must be established each year, and at dedicated land disposal sites where poor soil conservation greatly increases the expense of recovering and treating runoff. Application of sludge to saturated, snow-covered, or frozen ground greatly increases runoff, and is strongly discouraged.

Good *range management* practices are essential on sludge-amended pastureland. On overgrazed, poorly managed pastures, the amount of soil consumed by livestock may rise to over 10 times its normal level, greatly increasing the amount of sludge they ingest.

Monitoring requirements also vary greatly among options and site conditions, but some monitoring should always be considered a part of good practice. Dedicated land disposal sites may require the same degree of monitoring as landfills. Land reclamation, forest application, and agricultural application sites generally require intermittent monitoring. Groundwater monitoring should be conducted at sites where nitrogen is applied at rates in excess of crop needs. Land application monitoring may include soil metal levels and soil pH. Surface water and crop monitoring are often also required.

3.3.6 Sludge Quality

Land application employs soil as a treatment system and offers a means of utilizing sludge as a source of nutrients for plants and as a source of humus in conditioning soils. To use land application successfully, care must be taken with pathogenic organisms and toxic levels of certain organic chemicals and heavy metals. Each of these factors can be managed successfully.

Four approaches to land application have been described, each with special notes on the sludge quality factors that are important. In each approach, nitrogen loading limits should be considered, although they may not be the limiting factor. In agricultural land application, additional elements must be considered (see subsection 3.2.4).

Dedicated land disposal sites may require the same degree of monitoring as landfills. Here a soil auger is used to extract a soil sample at a dedicated land disposal site located next to a wastewater treatment plant.

3.3.7 Public Acceptance

Public acceptance—crucial to the success of any sludge use/disposal option—is particularly important when the voluntary use of sludge is being promoted. Public acceptance is gained by stressing the proven value of sludge as a resource, and is maintained by conscientious management and performance of operations. Public involvement in the decision-making process will help to minimize opposition and to identify the major roadblocks to local acceptance.

In agricultural application, the acceptance of local farmers is also of paramount concern. As mentioned earlier, the local Soil Conservation Service, county extension agents, and Farm Bureau can provide vital links with the farm community. However, continuing acceptance depends on maintaining a perception of quality in both management and product. Some cities, such as Milwaukee and Los Angeles, have been so successful in gaining public acceptance that they have created a product following, with demand often exceeding supply.

Site access is a key factor in public acceptance. Land application requires transport of sludge over good roads that are passable in most or all seasons. Trucking sludge through residential neighborhoods may generate public concern about traffic congestion, sludge spills, and dripping of sludge on the streets. Steps can be taken to assuage these concerns—for example, scheduling truck traffic at hours that will neither conflict with rush-hour traffic nor disturb sleeping residents, and washing trucks before they leave the site. One community fined trucks that dripped sludge, which has proven effective in reducing sludge spills.

3.3.8 Transportation Requirements

Transportation is a major expense in most land application systems. In agricultural application, where the sludge is often destined for many parcels of land, trucks are usually the most economical means of transport. For liquid sludge, tank trucks are commonly used. Even dewatered sludge requires watertight closed trucks. Open trucks with a tarp or similar covering can be used for composted and dried sludge. For dedicated land disposal sites pipeline transport may be possible. All transportation options are highly energy dependent, and none is cheap. The most appropriate mode of transport depends on the nature of the sludge and the distance to its destination.

3.3.9 Energy Usage

Except for transportation, energy usage in land application is low.

3.3.10 Regulatory Approval

Federal regulations pertaining to land application of sludge are contained primarily in 40 CFR 257—Criteria for Classification of Solid Waste Disposal Facilities and Practices. Many states also regulate sludge land application—some more stringently than the Federal government. Other requirements are contained in 40 CFR 761 and in hazardous waste rules under the Resource Conservation and Recovery Act.

In 40 CFR 257, land application is considered to be a form of solid waste disposal, as are landfilling and sludge lagooning. The same regulations, in several general sections, apply to all three practices.

- *Floodplains.* Land application sites, landfills, and lagoons may be located in a floodplain; however, they must not "restrict the flow of the base flood, reduce the temporary water storage capacity of the floodplain, or result in washout of solid waste, so as to pose a hazard to human life, wildlife, or land or water resources." A base flood is a 100-year flood.
- *Surface Waters.* Discharges that would violate Sections 402, 404, and 208 of the Clean Water Act are prohibited.
- *Ground Water.* Facilities must not "contaminate an underground drinking water source beyond the solid waste boundary." States may establish an alternative boundary for a facility if such a change would not contaminate drinking water resources. EPA is currently examining more stringent controls on land application to protect particularly vulnerable and valuable groundwater resources such as irreplaceable aquifers.
- *Public Health.* Waste cannot cause a risk of infection by the enteric organisms which are concentrated in the sludge. For this reason, controls on pathogenic organisms are required.

To protect public health, sewage sludge or septic tank pumpings that are applied to the land or incorporated into the soil must be treated by a *"Process to Significantly Reduce Pathogens"* (PSRP) prior to application or incorporation (see Table 6). The success of a PSRP can be determined by measuring the reduction in the number of organisms present. A one-log (90 percent) reduction in the number of pathogens present, or a two-log (99 percent) reduction in indicator bacteria (fecal coliforms) can be used to show that an unlisted process attains equivalent pathogen reduction. Also to protect public health, *public access* to the facility must be controlled for at least 12 months, and *grazing by animals* whose products are consumed by humans must be prevented for at least one month unless *"Processes to Further Reduce Pathogens"* (PFRP) are used (see Table 7).

Food-Chain Crops

Food-chain crops are: tobacco, crops grown for human consumption, and feed for animals whose products are consumed by humans. Land application of sludge for growth of food-chain crops is subject to additional requirements, and to restraints imposed by good practices and state regulations. For example, to prevent nitrate contamination of ground water, the usual practice is

Table 6. Regulatory Definition of Processes to Significantly Reduce Pathogens

Aerobic Digestion: The process is conducted by agitating sludge with air or oxygen to maintain aerobic conditions at residence times ranging from 60 days at 15°C to 40 days at 20°C, with a volatile solids reduction of at least 38 percent.

Air Drying: Liquid sludge is allowed to drain and/or dry on underdrained sand beds, or on paved or unpaved basins in which the sludge depth is a maximum of 9 inches. A minimum of 3 months is needed, for 2 months of which temperatures average on a daily basis above 0°C.

Anaerobic Digestion: The process is conducted in the absence of air at residence times ranging from 60 days at 20°C to 15 days at 35°C to 55°C, with a volatile solids reduction of at least 38 percent.

Composting: Using the within-vessel, static aerated pile, or windrow composting methods, the solid waste is maintained at minimum operating conditions of 40°C for 5 days. For 4 hours during this period the temperature exceeds 55°C.

Lime Stabilization: Sufficient lime is added to produce a pH of 12 after 2 hours of contact.

Other Methods: Other methods of operating conditions may be acceptable if pathogens and vector attraction of the waste (volatile solids) are reduced to an extent equivalent to the reduction achieved by any of the above methods.

Table 7. Regulatory Definition of Processes to Further Reduce Pathogens

Composting: Using the within-vessel composting method, the solid waste is maintained at operating conditions of 55°C or greater for three days. Using the static aerated pile composting method, the solid waste is maintained at operating conditions of 55°C or greater for three days. Using the windrow composting method, the solid waste attains a temperature of 55°C or greater for at least 15 days during the composting period. Also, during the high temperature period, there will be a minimum of five turnings of the windrow.

Heat drying: Dewatered sludge cake is dried by direct or indirect contact with hot gases, and moisture content is reduced to 10 percent or lower. Sludge particles reach temperatures well in excess of 80°C, or the wet bulb temperature of the gas stream in contact with the sludge at the point where it leaves the dryer is in excess of 80°C.

Heat treatment: Liquid sludge is heated to temperatures of 180°C for 30 minutes.

Thermophilic aerobic digestion: Liquid sludge is agitated with air or oxygen to maintain aerobic conditions at residence times of 10 days at 55°C to 60°C, with a volatile solids reduction of at least 38 percent.

Other methods: Other methods or operating conditions may be acceptable if pathogens and vector attraction of the waste (volatile solids) are reduced to an extent equivalent to the reduction achieved by any of the above methods.

Any of the processes listed below, if added to a PSRP, further reduce pathogens.

Beta ray irradiation: Sludge is irradiated with beta rays from an accelerator at dosages of at least 1.0 megarad at room temperature (ca. 20°C).

Gamma ray irradiation: Sludge is irradiated with gamma rays from certain isotopes, such as ^{60}Cobalt and ^{137}Cesium, at dosages of at least 1.0 megarad at room temperature (ca. 20°C).

Pasteurization: Sludge is maintained for at least 30 minutes at a minimum temperature of 70°C.

Other methods: Other methods or operating conditions may be acceptable if pathogens are reduced to an extent equivalent to the reduction achieved by any of the above add-on methods.

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to apply sludge at a rate that just satisfies the nitrogen requirement of the crop to be grown on a site. Similarly, some states protect surface waters against phosphorus contamination by limiting application rates to the phosphorus needs of the crops. Key Federal regulations affecting land application to food-chain crops focus on pathogen reduction, cadmium limitations, and PCB content.

If the sludge will not contact the edible portions of the crop, *pathogen reduction* to PSRP levels is acceptable. However, if crops for direct human consumption are grown within 18 months of sludge application, sludge must be treated with a PFRP. These processes destroy pathogenic bacteria, viruses, and protozoa, as well as parasites, in most cases by exposing the sludge to elevated temperatures over a period of time.

Food-chain application is also subject to regulations designed to prevent excessive human exposure to *cadmium*. Annual cadmium applications to sites growing tobacco, root crops, and leafy vegetables are limited to 0.5 kg/ha/yr. Cadmium application to sites growing other crops are limited to 1.25 kg/ha/yr until 1987, when the limit will drop to 0.5 kg/ha/yr. The cumulative application of cadmium is also limited, based on soil pH and soil cation exchange capacity. In general, soil pH must be at least 6.5 or greater at the time of planting, and EPA recommends that pH be permanently maintained at or above 6.2. Future regulations may reflect greater flexibility in this requirement.

Alternatively, if the crop is exclusively animal feed, cadmium applications need not be limited, but pH must be consistently maintained at or above 6.5. Thus the production of animal feed is ideal at dedicated land disposal facilities. However, such facilities do require a facility operating plan which demonstrates how the animal feed will be distributed to preclude ingestion by humans and which describes measures to safeguard the public health from the hazards of cadmium entering the food chain. Also, future property owners must be notified, by means of a stipulation in the land record or property deed, that the property has received solid waste at high cadmium application rates and that food-chain crops should not be grown.

Sludges containing greater than 10 mg/kg but not more than 50 mg/kg of *PCBs* must ordinarily be incorporated into the soil when applied to land used for producing animal feed, including pasture crops for animals raised for milk. Sludges containing greater than 50 mg/kg of PCBs must be treated under the strict requirements of 40 CFR 761.60 which allows only incineration (in compliance with Part 761.70) or disposal in a chemical waste landfill (defined under Part 761.65). These requirements are separate from hazardous waste requirements specified under RCRA. Substitute methods of disposal may be approved by EPA Regional Offices.

Sludges that contain high concentrations of metals and thus qualify as hazardous wastes are controlled under provisions of the Resource Conservation and Recovery Act (see subsection 2.3.4).

3.3.11 Cost Factors

Land application may be a low-cost sludge use option. Capital expenditures are frequently low, particularly if the municipality does not need to buy land. *Capital costs* include:

- Trucks
- Sludge storage facilities
- Dewatering/drying equipment
- Stabilization/composting equipment
- Spreading equipment
- A small amount of land on which to set up or store the equipment and facilities.

Dewatering, drying, and composting may all require high capital expenditures, but are often not used in land application.

Operating and maintenance costs are generally a substantial part of the overall cost of a land application program. In particular, because of the predominance of transportation costs, recent increases in energy prices have raised the overall operating costs of land application. Despite such setbacks, land application is still the lowest cost option for many communities.

3.4 Case Study: Agricultural Application

Salem, Oregon, generates 121,120 cubic meters (m^3) [32 million gallons (mil gal)] of 2.7 percent solids, anaerobically digested sludge per year. In 1976, it initiated a program of sludge application to agricultural land. Known as BIOGRO, this program now recycles 90 to 95 percent of Salem's sludge to local farmland.

Typical sludge characteristics are shown in Table 8. The sludge nitrogen levels are raised by the addition of ammonia during the treatment process.

In 1982, sludge was applied to approximately 1,200 ha (3,000 ac) of local agricultural land. Application sites are located as far as 32 kilometers (km) [20 miles (mi)] from the treatment plant, but the majority are located within an 11-km (7-mi) radius of the treatment plant. At virtually all sites, the sludge is applied only once per year.

Sludge application rates are based on the nitrogen needs of the crop and the nutrient content of the sludge. They average approximately 3.4 dry mt/ha (1.5 dry tons/ac), and vary from 2.2 dry mt/ha (1 dry ton/ac) to 6.3 dry mt/ha (2.8 dry tons/ac).

Table 8. Characteristics of Digested Sludge at Salem, Oregon, Willow Lake Wastewater Treatment Plant[a]

Constituent	Concentration[b]
pH	7.3
Total solids	2.5%
Total nitrogen	10.3%
Ammonia-nitrogen	5.9%
Phosphorus	2.0%
Potassium	0.96%
Zinc	980 mg / kg
Copper	470 mg / kg
Nickel	43 mg / kg
Cadmium	7 mg / kg
Iron	21,000 mg / kg
Lead	230 mg / kg
Barium	720 mg / kg
Chromium	60 mg / kg
Magnesium	200 mg / kg
Calcium	12,200 mg / kg
Sodium	3,000 mg / kg
Arsenic	0.1 mg / kg
Cobalt	8 mg / kg

[a] All constituents except pH reported on a dry weight basis.

[b] Based on samples from early 1983.

SOURCE: Reference (11).

3.4.1 Crop Choice and Site Selection

The sludge is applied primarily to fields used to produce grains, grasses, pasture, and silage corn. Sludge-amended sites are also used to produce seed crops, Christmas tree farms, commercial nurseries, and filbert orchards. No sludge is applied to fruit and vegetable crops. For poorly drained soils, sludge can generally only be applied from April 15th through October 15th. For well-drained soils, sludge can be applied anytime except during or immediately after rainstorms. Schedules for application of sludge to soils with intermediate drainage capacity fall between these two extremes. Cation exchange capacity is used to limit cumulative metal loadings added by sludge application (see Table 9). However, if soil pH is less than 6.5, as it is in most of the Salem area, then cumulative Cd addition is limited to 4 kg/ha (4.5 lb/ac), regardless of soil cation exchange capacity. Since the sludge generated by Salem is very low in metals, application sites generally have a life well over 25 years. The BIOGRO program keeps records of the annual sludge application to each site, including quantities per hectare of dry solids, total nitrogen, ammonia nitrogen, and the various heavy metals.

Table 9. Maximum Cumulative Heavy Metal Loadings Recommended[a] for Sludge Application to Privately Owned Agricultural Land at Salem, Oregon

Cation exchange capacity (milli-equivalents/ 100 grams)	Metal loading [kg/ha (lb/ac)]				
	Pb	Zn	Cu	Ni	Cd[b]
<5	500 (447)	250 (223)	125 (112)	50 (45)	5 (45)
5 - 15	1,000 (893)	500 (447)	250 (223)	100 (89)	10 (9)
>15	2,000 (1,786)	1,000 (893)	500 (447)	200 (179)	20 (18)

[a] Oregon Administrative Rules, Chapter 340, Division 50.

[b] If soil pH is below 6.5, maximum Cd limitation is 4 kg/ha (4.5 lb/ac) regardless of soil cation exchange capacity.

Each sludge application site is investigated by the Oregon Department of Environmental Quality (DEQ), which makes recommendations on a case-by-case basis. General guidelines are as follows:

- Minimum distance to domestic wells = 61 m (200 ft).
- Minimum distance to surface water = 15 m (50 ft).
- Minimum rooting depth (effective depth of soil) = 0.61 m (2 ft).
- Minimum depth to ground water at time that sludge is applied = 1.22 m (4 ft).

- Minimum distance of sludge application to public access areas varies with the method of sludge application:
  - If sludge is incorporated into soil = 0.
  - If sludge is not incorporated into soil = 30.5 m (100 ft).
  - If sludge is pressure-sprayed ("big gun"-type sprayer) over the soil = 91 to 152 m (300 to 500 ft).
- Sludge application is not approved close to residential developments, schools, parks, and similar areas.
- Minimum slope is largely left to the investigator's discretion. Where no surface waters are endangered, slopes as high as 30 percent have been approved. Generally, however, the maximum allowable slope is 12 percent and, in cases where sensitive surface waters are nearby, maximum slopes may be held to 7 percent or less.

3.4.2 Sludge Application

Sludge is hauled and applied to agricultural land virtually year round in the Salem BIOGRO program. All hauling is done by a fleet of four tanker trucks with a useful capacity of 20,000 l (2,500 gal) each.

In general, pasture and grass land receive sludge applications during the winter months; agricultural land growing seasonal crops receives sludge during the warmer months, before planting or after harvesting. When weather prevents sludge application, the sludge is stored in lagoons at the treatment plant.

Sludge is usually applied by haul trucks themselves. If the application site soil is too wet or otherwise unsuitable for direct truck access, then the sludge is sprayed onto the application site. In this procedure, the haul truck is parked as close to the application site as practical and connected sequentially to a short discharge hose, a portable pump, portable aluminum pipe (if necessary), a 200-m (600-ft) long hose, and a big gun sprinkler capable of spraying liquid sludge in a 37-m (120-ft) radius.

City employees do all the sludge hauling and spreading. Three drivers are used year round, and two additional temporary drivers are added during the summer months when sludge volume and distribution activity increase.

Application of liquid sludge from a tanker truck to agricultural land in Salem's BIOGRO program.

3.4.3 Monitoring

During the early years of the BIOGRO program, the city routinely analyzed the sludge-amended soil. Results showed virtually no change in soil chemical and physical characteristics, so the city no longer routinely monitors soils, but many farmers have their soils tested periodically by laboratories as a prudent agricultural practice.

During the early years of the BIOGRO program, ground water from wells on or within 150 m (500 ft) of sludge application sites was sampled and analyzed before and after application. Since results showed no significant changes in groundwater quality over a period of 3 years, the groundwater monitoring program has been gradually reduced. Selected wells are now sampled approximately every 3 years.

The City of Salem and the Oregon DEQ report that background levels of nitrate nitrogen were very high in groundwater samples obtained from many wells in the area north of the treatment plant. These high nitrate nitrogen levels are thought to be due to the soil characteristics in this area and the application of commercial fertilizers over long periods. To avoid future claims of groundwater degradation, the BIOGRO program does not apply sludge in this area.

The BIOGRO program conducted some limited crop tissue sampling and analysis during the initial years of the program. Constituents analyzed included boron, cadmium, copper, magnesium, nickel, zinc, arsenic, lead, molybdenum, and selenium. Results showed no significant difference between crops grown on sludge-amended soils and control crops.

Application sites are selected to avoid the possibility of surface water contamination, and no surface water monitoring is routinely conducted.

3.4.4 Costs

Annual costs for the BIOGRO program are approximately $320,000, including depreciation on capital equipment. This translates to a cost of about $106/mt ($97/ton) of sludge solids.

3.5 Case Study: Land Reclamation

In Venango County, Pennsylvania, sludge from local towns was used to reclaim a bank of bituminous coal strip mine spoil—unwanted materials removed from the ground during mining and discarded on the surface. The site had been mined for coal and, prior to this project, was essentially barren despite three previous attempts to reclaim the area using commercial fertilizer. Sludge was initially applied on a small scale to demonstrate the feasibility of sludge-based land reclamation. The pilot project was so successful that the mine owner decided to reclaim the entire site. The positive results of this reclamation effort and several other demonstration projects were factors in the State of Pennsylvania's decision to allow the use of wastewater sludge to reclaim more than 1,200 ha (3,000 ac) of mined land, and to actively encourage this as a means of land reclamation.

3.5.1 Preliminary Preparations

Liquid and dewatered sludges for the demonstration project were obtained from three local treatment plants and analyzed to determine their acceptability for land application. Four 1-ha (2.5-ac) plots were laid out and marked for sludge application. Two of these plots received liquid digested sludge, the other two received dewatered sludge. Prior to application, a portion of the demonstration area was scarified with a tractor and chisel plow to loosen the compacted spoil material and decrease the potential for sludge runoff during heavy rains.

Soil analyses indicated that the average site soil pH was 3.9. The Pennsylvania Department of Environmental Resources requires that soil pH be at least 6.5 for use of sludge in land reclamation projects. Therefore, agricultural lime was applied at an average rate of 12.3 mt/ha (5.5 ton/ac) to raise the soil pH to 6.5.

Diversion ditches were installed to prevent sludge runoff in the direction of the two lakes on the property. A berm was constructed on three sides of the dewatered sludge unloading and storage area to prevent sludge migration.

3.5.2 Sludge Application and Incorporation

The liquid and dewatered sludges were mixed on site prior to application. Average solids content for the liquid digested sludge was 3 percent and for the dewatered sludge was 52 percent. Average total nitrogen content was 1.3 percent for the dewatered sludge and 2.7 percent for the liquid digested sludge.

Metals loading rates were well within EPA- and state-recommended levels, except for copper which slightly exceeded the Pennsylvania recommendation of 112 kg/ha but was well within the EPA guideline of 250 kg/ha. The highest sludge application rate was equivalent to applying 10 mt/ha (4.5 ton/ac) of an 11-9-0 (N-P-K) commercial fertilizer.

In May 1977, liquid digested sludge was hauled in tank trucks from the towns of Farrell and Oil City, mixed on site in a plastic-lined holding pond, and spread onto two plots with a vacuum tank liquid manure spreader at rates of 7 and 11 dry mt/ha (3 and 5 tons/ac), respectively.

A total of 588 wet mt (647 tons) of dewatered sludge was transported by coal trucks to the site, mixed with a farm manure spreader, and applied to two plots at rates of 90 and 184 dry mt/ha (40 and 82 tons/ac) respectively. The dewatered sludge was then incorporated into the surface with a tractor to a depth of 10 cm (4 in).

3.5.3 Seeding and Mulching

The sludge-treated areas were broadcast seeded with a mixture of two grasses and two legumes. The two grass species germinated quickly, and provided a complete protective cover during the first year, allowing time for the two legume species to become established and develop into the final vegetative cover.

3.5.4 Monitoring

Vegetation growth responses were evaluated at the end of each growing season. All sludge-treated areas had a complete cover of vegetation within 3 months of sludge application, and vegetation growth continually increased during the following 4 years with no additional sludge applications. In comparison, untreated portions of the site remained barren.

The two grass species were dominant initially; however, legumes had begun to predominate by the third season. Within 5 years the grass species were almost completely replaced by permanent legume species.

Samples of vegetation showed trace metal concentrations well below the levels that might impair crop growth.

Spoil samples were collected at various locations and depths at the end of each year. Surface spoil pH generally increased during the 5 years following sludge application. Even at the highest sludge application rate [184 mt/ha (82 ton/ac)], the trace metal concentrations in the surface spoil [0 to 15 cm (0 to 6 in)] were only slightly increased, and were low in comparison to normal ranges for soils. Nitrate nitrogen levels in soil percolate water at a 90-cm depth increased to up to 34 mg/l shortly after application, but decreased to well below 10 mg/l within 5 months of application, by which time vegetative cover was well established.

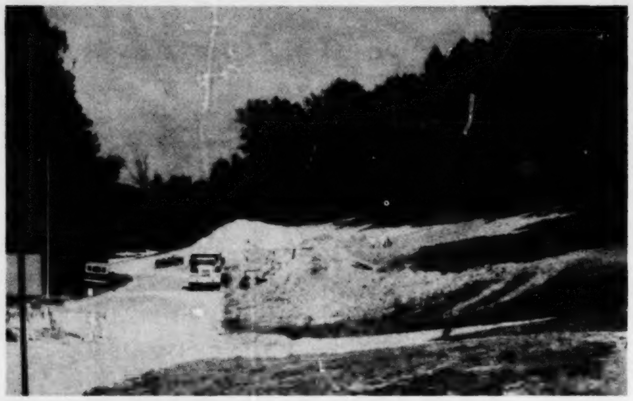
Groundwater analysis taken at the edge of the site for a 4-year period indicated that metals concentrations, fecal coliforms, and nitrate nitrogen levels in ground water did not increase, even at the highest application rates.

4. Distribution and Marketing of Sludge Products

4.1 Introduction

Distribution and marketing (D&M) of sludge products is a widely employed sludge use option, and its use is growing. Like land application, distribution and marketing employs the soil conditioning and fertilizer value of sludge beneficially. In a typical D&M program, sludge products are sold or distributed free to commercial growers, landscaping firms, parks, highway departments, cemeteries, and the public.

Many of the benefits and concerns associated with land application also apply to distribution and marketing. No Federal regulations currently cover this activity; the practices recommended here are advisory, based on reviews of many successful programs. Because of the high potential for public contact with the sludge, only sludges that meet PFRP criteria (Table 7) should be used in D&M programs. Heat-dried or composted sludges usually meet these criteria and are typically used because they have a high solids content and are therefore more easily handled by the user.

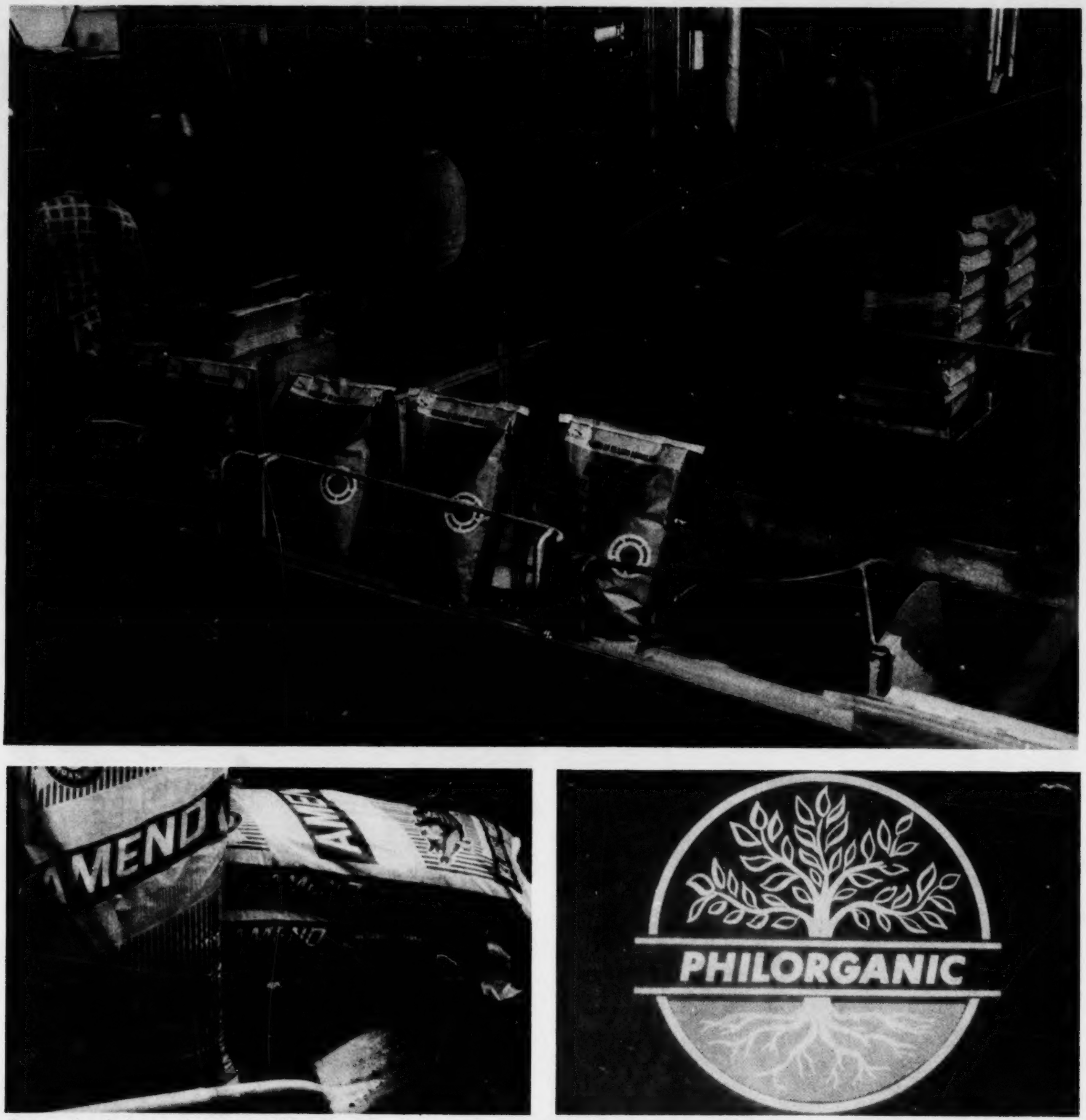


Application of sludge compost in September to landscape a road shoulder in Maryland.

By November, lush grass had entirely covered the site.

Use of sludge compost to recondition a tourist-worn lawn surrounding Maryland's state capitol at Annapolis.

Sludge products are applied to lawns, shrubs, ornamental plants, and vegetable gardens. Application to vegetable gardens is not usually recommended because the amount applied cannot be controlled as it is in large-scale land application programs, raising the possibility that high levels of heavy metals might be applied to a given plot of ground. Sludge products are distributed in bulk or in bags. Bags are common since they facilitate distribution. For example, Milorganite, a heat-dried sludge produced in Milwaukee, Wisconsin, is sold as a bagged product in every state as a soil conditioner. Other cities that distribute heat-dried sludge include Chicago, Illinois; Houston, Texas; Largo, Florida; Newport News, Virginia; and the Greater Atlanta, Georgia, area. Municipalities that distribute composted sludge include Philadelphia, Pennsylvania; the District of Columbia; Kittery, Maine; Topeka, Kansas; Salt Lake City, Utah; Columbus, Ohio; Missoula, Montana; Portland, Maine;



Among the sludge products currently marketed are Milorganite, *a heat-dried sludge produced by Milwaukee, and* Amend, *a product of windrow composting at the Los Angeles County Sanitation District.* Philorganic *is the distinctive logo used to market Philadelphia's compost product.*

Portland, Oregon; and the Greater Los Angeles, California, area. Some of these municipalities contract with an intermediary for distribution.

Because dried or composted sludge may be used on urban open spaces such as lawns, golf courses, nurseries, cemeteries, or school fields, distribution and marketing is a particularly appropriate option for localities that do not have the land available for conventional land application. Although the municipality may receive some return on the sale of sludge products, these revenues do not usually cover the costs of treating, distributing, and marketing the sludge product. Consequently, a decision on the area to be included in the marketing effort should take into account such factors as the cost of shipping and the possibility of reaching buyers who may be willing to pay a higher price for the product.

In most D&M programs, the municipality has little control over what is ultimately done with the sludge, so only generalized analysis of the environmental impacts of sludge application is possible. Due to the low level of control achievable, D&M is most appropriate for sludges with low levels of heavy metals and toxic organic compounds. If bagged, use instructions should be printed on the bag. If the product is distributed in bulk, literature on appropriate uses should be provided to all recipients.

The problems and concerns involved in setting up a distribution and marketing program center around ensuring that a high quality product is available, and effectively developing a market for that product. Other important concerns include maintaining good public relations and ensuring that the operations are acceptable to the community.

The key factor in the success or failure of a distribution and marketing program is product demand. Many D&M programs use surveys to identify potential users, and some hire people with experience in setting up similar marketing efforts. Distribution and marketing programs usually assign a trade name to the dried or composted sludge to enhance its marketability. Some of these names include ComPRO, Eko-Kompost, ComTil, Hou Acnite, Earth Life, and Philorganic in addition to Milorganite.

Product quality is a key factor in maintaining product demand (see subsection 4.3.5). In most communities using D&M, sludge products have competed successfully against other soil conditioners, topsoil substitutes, and potting media. In some localities, demand for the product has exceeded supply. But in other municipalities D&M programs have failed due to poor or inconsistent product quality or due to operations that were not acceptable to the community.

The demand for sludge products tends to be highly seasonal, with peaks in the spring or fall. However, local factors such as climate or a year-round specialized market may serve to either accentuate or alleviate the seasonality of the market.

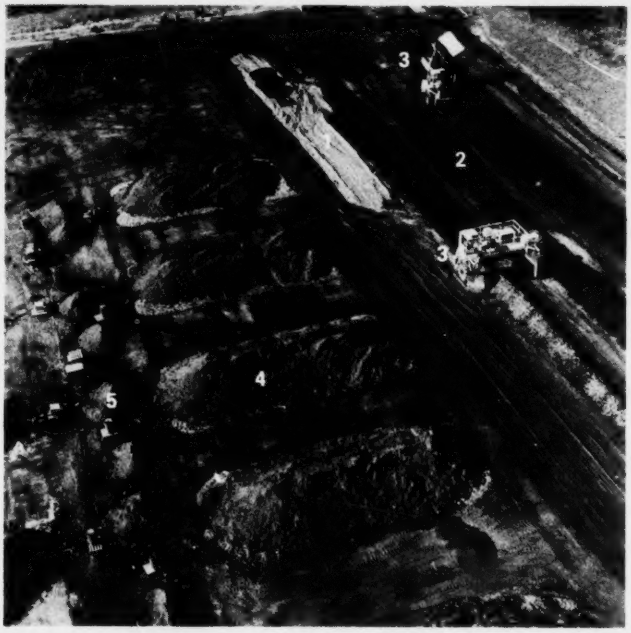
4.2 Process and Performance

Typically, either composted or heat-dried sludge products are used in distribution and marketing. Air-dried sludge is sometimes used, but is considered less suitable because it is unlikely to meet the PFRP criteria specified (see Table 7) without additional processing.

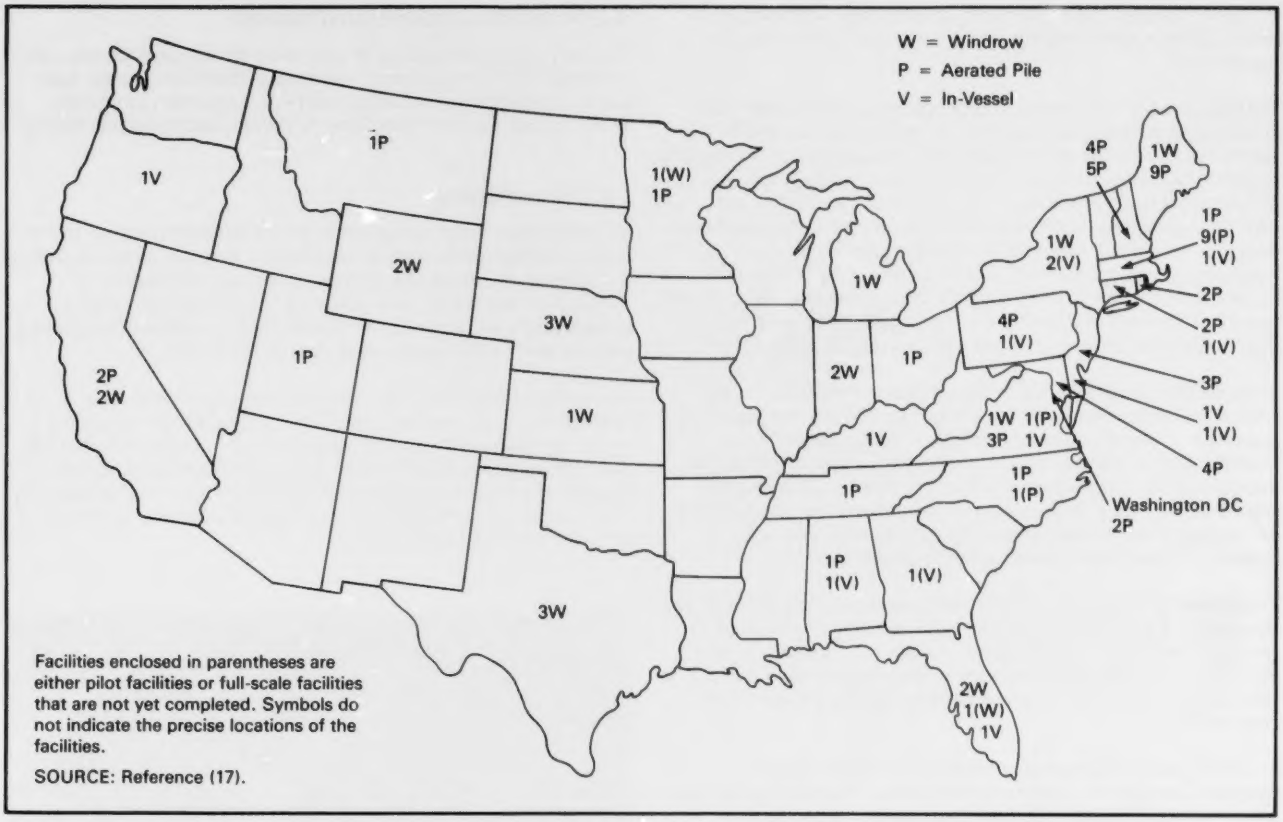
4.2.1 Composting

In wastewater sludge composting, the sludge is dewatered, mixed with a bulking agent, such as wood chips, bark, shredded tires, rice hulls, straw, or previously composted sludge, and allowed to decompose aerobically for a period of time. Three composting processes are employed in the United States: windrow composting, aerated piles, and in-vessel composting (Figure 10).

In *windrow composting*, the sludge-bulking agent mixture is formed into long, open-air piles. The sludge is turned frequently to ensure an adequate supply of oxygen throughout the compost pile and to ensure that all parts of the pile are exposed to temperatures capable of killing all pathogens and parasites. Windrow composting may be adversely affected by cold or wet weather and is difficult to control when raw sludge is used.



Sewage sludge composting at Beltsville, Maryland. Sludge is first mixed with wood chips (1), then either placed into windrows (2) and aerated by two large machines (3), or placed into static piles (4) and aerated with pumped air which exits through odor control piles (5).



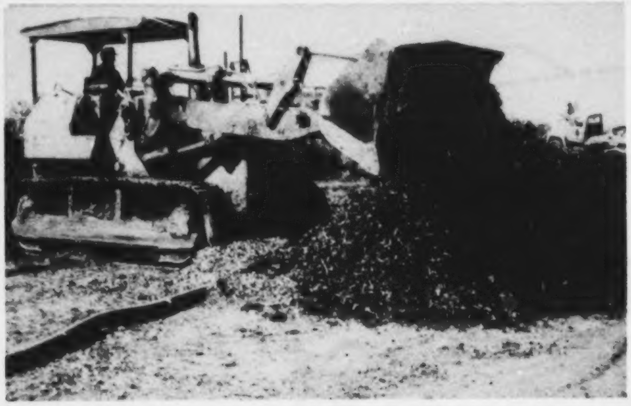
Facilities enclosed in parentheses are either pilot facilities or full-scale facilities that are not yet completed. Symbols do not indicate the precise locations of the facilities.

SOURCE: Reference (17).

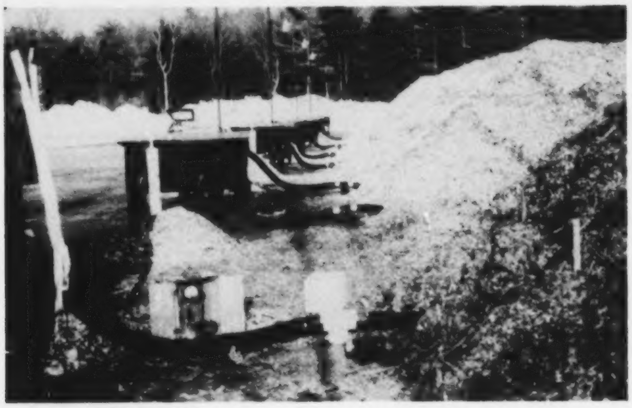
Figure 10. Location of Wastewater Sludge Composting Facilities in the Contiguous United States

Aerated piles, also called static piles, are rectangular piles that are supplied with air via blowers connected to perforated pipes running under the piles. The blowers draw or blow air into the pile, assuring even distribution of air throughout the composting sludge (18). A layer of previously composted sludge placed over the surface of the pile helps to insulate the pile and assure that sufficient temperatures are achieved throughout the pile (Figure 11). Because the piles do not have to be turned, and because the sludge is insulated by the outer layer of previously composted sludge, static pile composting is less affected by inclement weather than windrow composting. As in windrow composting, the sludge must be mixed with a bulking agent to lower the moisture content and to enhance sludge porosity so that air can be drawn through the entire pile. Aerated pile composting has been studied extensively at the U.S. Department of Agriculture in Beltsville, Maryland; at Rutgers—the State University of New Jersey; at Ohio State University; and at the University of California at Berkeley.

The first step in aerated pile composting is mixing the sludge and bulking agent—in this case, wood chips. Here sludge is laid out on a bed of wood chips in preparation for mixing.



Bulldozers are commonly used to mix and build aerated piles.



Piles are constructed atop perforated pipes connected to blowers which draw or blow air through the piles.

In-vessel composting takes place in completely enclosed containers, where environmental conditions such as temperature and oxygen supply can be closely monitored and controlled. This process is particularly viable for municipalities in cold climates or where land is limited. Many in-vessel systems are operational in Europe and, as of 1984, several in-vessel systems are under construction in the United States.

The objective in all composting systems is to allow thorough aerobic decomposition of sludge to produce a humus-like product resembling soil. Sludge is typically composted for 21 to 30 days, during which time pile temperatures typically reach 55°C in a properly run operation. (The exact amount of time required varies with the composting method.) The compost is then allowed to cure for an additional 30 days, and is often stored for 60 to 90 days following curing to ensure that the final product has no residual odors. The product is screened before or after curing to remove as much bulking agent as possible. The high temperatures achieved

After 21 to 30 days of composting, the sludge is formed into curing piles to allow additional stabilization. Typically, the composted mixture will remain in a curing pile like this one for approximately 30 days.

Compost is screened before or after curing to separate the compost from the bulking materials.

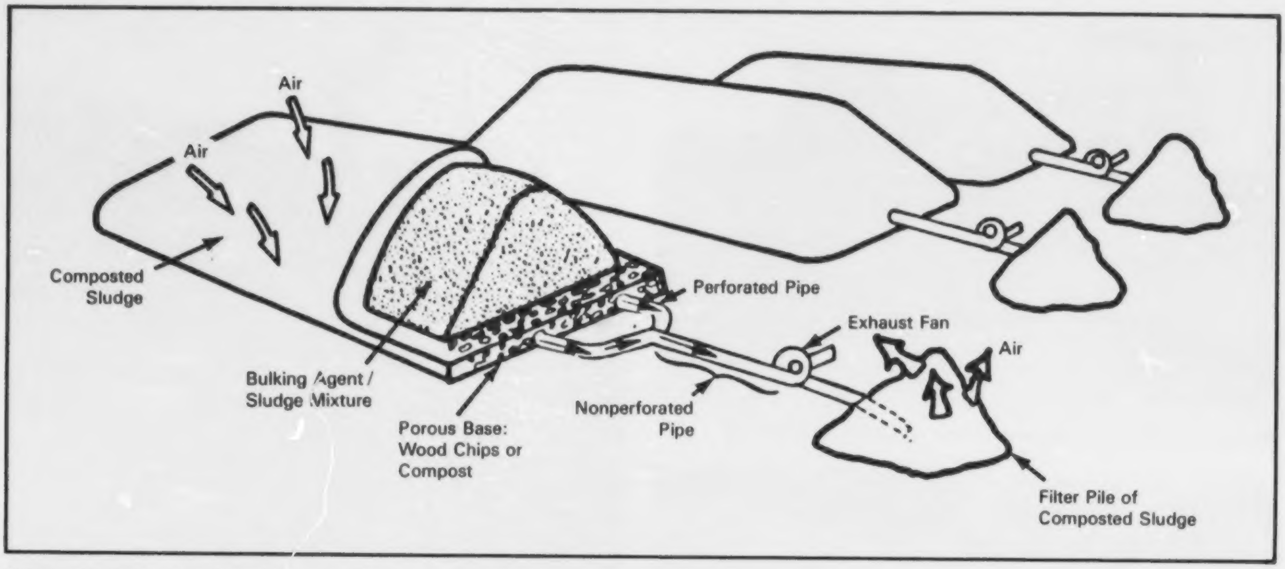
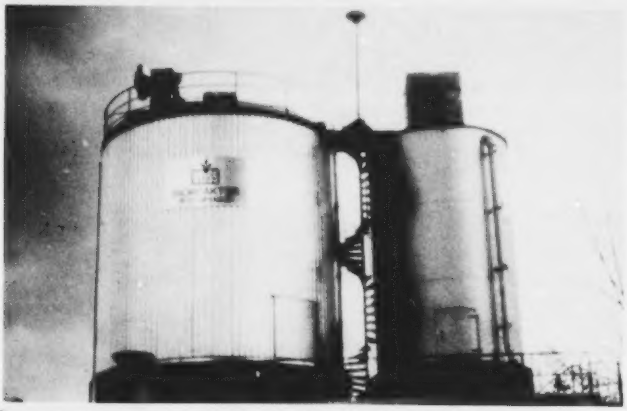

Air
Air
Composted Sludge
Bulking Agent / Sludge Mixture
Porous Base: Wood Chips or Compost
Perforated Pipe
Exhaust Fan
Air
Nonperforated Pipe
Filter Pile of Composted Sludge

Figure 11. Aerated Static Pile Composting



In-vessel composting system in Horn, Federal Republic of Germany.

Interior of Compost Systems Company in-vessel composting system in South Charleston, Ohio.

during composting destroy virtually all pathogens and parasites; however, compost is a suitable medium for the regrowth of bacteria, and care must be taken to keep it from becoming contaminated (see subsection 4.3.5).

During composting, the organic material in the sludge is degraded to a humus-like material that makes an excellent soil conditioner. The bulking agent is also partially digested (19) and, despite screening, adds appreciably to the volume of the material that must be marketed. Compost has a lower level of available nitrogen than other forms of sludge due to preprocessing of the sludge via conditioning and dewatering, dilution of nutrients by bulking material, and loss of ammonia nitrogen during the composting process. However, it is an excellent soil conditioner and its nutrients become available slowly over several years. Additionally, by promoting a healthy soil microflora, compost can help to prevent plant diseases (12).

Additional details of the various composting methods can be found in references (4,12,20,21).

Proper composting of municipal wastewater sludge results in an earth-like product that resembles fertile soil in both texture and odor.

4.2.2 Heat Drying

Heat drying involves removing water from the sludge at high temperatures. Energy costs are a major consideration in the selection of this process. Some municipalities have used the waste heat from thermal processes, such as solid waste incineration, to dry sludge.

Heat drying at above 80°C (176°F) for very short periods destroys all pathogens in sludge and greatly reduces sludge volume by removing most of the water. Heat-dried sludge contains 4 to 6 percent nitrogen—a level comparable to liquid digested sludge. Most of the nitrogen is in the form of organically bound nitrogen that is present in high levels in raw waste-activated sludge—the sludge most commonly used for heat drying. Ammonia nitrogen is lost in the drying process. Guidance on design of heat-drying processes is provided in reference (4).

4.2.3 Air Drying

Air drying rapidly reduces sludge water content in dry climates. The process is usually inexpensive; however, it does not destroy pathogens as effectively as do the listed PFRP technologies (see Table 7). For this reason, air-dried sludges should not be distributed or marketed to the general public. They are, however, suitable for application to land under more controlled conditions.

4.3 Key Parameters

4.3.1 Treatment Requirements

If food-chain crops are to be grown on sludge-amended soil very shortly after the sludge application, Federal regulations require that the sludge be subjected to a process that reduces pathogens to PFRP levels (Table 7). Sludge products used in D&M programs may present these same exposures and should be subjected to the same level of treatment. The sludge product should usually be fairly dry to facilitate handling by the user. Dewatering is therefore generally employed prior to heat drying and composting.

4.3.2 Community Size

Distribution and marketing is most widely used by mid-sized to large municipalities. Small municipalities often rely on the informal giveaway of air-dried sludge or are likely to find direct land application a more economically acceptable option.

4.3.3 Land Requirements

Distribution and marketing requires only a small amount of land—that needed for composting or heat-drying facilities. If drying beds are used, between 9 and 20 m^2/mt (90 and 200 sq ft/ton) of dry sludge solids are required in the northern United States (2).

4.3.4 Storage Requirements

Significant storage capacity is present in the composting process itself. Often, however, 6 to 9 months' worth of storage beyond that provided by the process may be necessary. The amount of storage needed is highly site specific and depends on such factors as climate and the presence of year-round markets such as nurseries. To maintain product quality, storage facilities should protect the finished compost from contamination and precipitation. Wet compost is heavy and generally less desirable to end-users.

Some storage of sludge prior to composting may also be necessary to facilitate system operation and to allow greater flexibility in transporting the sludge from the treatment plant to the composting facility. In addition, storage capacity for the untreated sludge is desirable as a contingency in case of system malfunctions, unless there are alternative options for sludge use/disposal during periods of disrupted operations.

4.3.5 Good Practices

Quality control is crucial to maintaining a strong demand for the product. Since even a well-run composting program may occasionally encounter quality control problems, all products should be monitored for quality, and provisions should be made for disposing of compost that does not meet the quality control standards. The key factors of good practices in composting are ensuring the quality of incoming sludge; using trained and conscientious operators; allowing adequate composting and curing times; maintaining aerobic conditions and adequate temperatures during composting; and keeping the finished product dry during storage.

Heat drying, like incineration, is a high technology process that requires careful equipment maintenance and well-trained operators. Controlling dust during sludge handling can be a problem. In addition, extremely dry sludge is quite flammable, and when dried to form dust, is explosive.

Quality control for pathogen reduction can be achieved by monitoring the high temperatures achieved in the process. In both composting and heat-drying operations, care should be taken to prevent contamination of the finished product. Procedures to accomplish this objective include using different equipment for handling the raw sludge and the finished product, washing equipment regularly, and promptly cleaning up sludge spills. Recontamination in air-dried sludge is less of a problem than in compost because bacteria do not survive well in such dry material.

A laboratory technician at the Agricultural Research Center in Beltsville, Maryland, measures water uptake of grasses and soybeans fertilized with composted sludge applied to soil at different rates. These tests enable scientists to determine the proper amounts of composted sludge for fertilizing various crops.

4.3.6 Sludge Quality

Because sludge products may be applied at very high rates and may be handled by users, sludge quality is very important. Only sludges with low metal concentrations should be distributed or marketed, and these should be processed to eliminate pathogenic organisms. When pathogen levels are reduced below detectable levels and the end product is applied in small quantities, there is little potential for harmful effects on human health or the environment from these products.

Since garden produce forms a significant portion of the diet of some families, there is a slight potential health hazard from the continued use of sludge products containing high metals levels. Some distribution and marketing programs recommend not applying sludge to vegetable gardens; others offer guidelines for garden application.

Lead levels are particularly important. Some children consume nonfood substances such as soil and paint chips—a behavior known as pica. Use of sludge products in lawns and parks increases the potential for exposure of these children to the heavy metals in sludge. Given the well-documented adverse effects of lead on the development of children, sludges with low lead levels are preferable for D&M.

Maximum levels of heavy metals considered suitable for unrestricted distribution of wastewater sludge compost have been published by USDA (12), by the Maryland Environmental Service (MES) (19), and others. These concentrations are:

- cadmium—12.5 to 30 mg/kg
- copper—500 to 900 mg/kg
- lead—285 to 1,000 mg/kg (MES)
- nickel—100 to 200 mg/kg
- zinc—1,250 to 1,800 mg/kg
- mercury—5 mg/kg.

One occupational health concern that may be raised in connection with composting is the presence of *Aspergillus fumigatus. Aspergillus fumigatus* is a very common fungus found in many locations such as basements, farm buildings, and wooded areas. During certain composting operations, particularly woodchip handling, elevated levels of *Aspergillus* may occur (22). In susceptible individuals, such as chronic asthmatics and patients receiving immunosuppressive therapy, infection by *Aspergillus* spores can deteriorate respiratory function, resulting in a condition known as aspergillosis. In a few such cases, this condition has led to serious illness and even death. However, aspergillosis is not normally observed in healthy individuals. When it does occur in healthy individuals, the symptoms are usually mild and disappear after exposure to the spores is eliminated (23).

Elevated *Aspergillus* levels have been observed at composting sites when mixing sludge with the bulking agent and when mixing compost piles; these levels are comparable to those encountered in walking through a pile of decaying leaves (22). Levels rapidly return to background concentrations after such operations are completed. Composting presents little additional risk of aspergillosis to citizens living near the site; however, as a precaution composting facilities should not be located in the immediate vicinity of nursing homes or hospitals (22). To protect workers at the facility, individuals who have a history of allergic sensitivity, have had recent renal or cardiac disease, or are undergoing immunosuppressive therapy should not be hired. As an additional precaution, front-end loaders can be equipped with enclosed, air-conditioned cabs, or workers can be provided with dust-filtering masks (22).

4.3.7 Public Acceptance

Distribution and marketing programs have generally been well accepted by the public and by horticultural professionals. Public concerns over environmental problems are generally low. Many localities have demonstrated a high demand for composted or dried-sludge products.

4.3.8 Transportation Requirements

Transportation is important in large-scale distribution and marketing operations. In addition to considering the cost of transportation of the sludge or sludge product from the wastewater treatment plant, planners must consider the transportation of bulking materials and the distribution of the finished product.

4.3.9 Fuel Usage

Heat drying requires large amounts of energy. Composting uses less fuel and electric power than heat drying, but fuel and power for dewatering the sludge, and constructing and aerating the piles are significant costs in these operations.

4.3.10 Regulatory Approval

Distribution and marketing of sewage sludge is technically covered under the same regulations as land application (subsection 3.3.10), but EPA plans to promulgate regulations better adapted to the uncontrolled use and frequent human contact that characterize the use of these products. These regulations may detail more specific criteria for sludge quality in D&M programs.

4.3.11 Cost Factors

The costs of a distribution and marketing program may be high relative to the costs of direct land application. Major *cost* factors include:

Dewatering
Composting or heat drying
Market development
Shipping.

The first two components involve significant capital expenditures, and all components can generally affect total operating costs.

As part of a public acceptance program, site personnel take air samples from a windrow at the Los Angeles County Sanitation District facility. Samples are checked for odors.

4.4 Case Study

"Site II" is an aerated static-pile composting facility located in Silver Spring, Maryland, and operated by the Washington Suburban Sanitary Commission (WSSC). Currently the facility is operating below its designed capacity of 360 wet mt (400 wet tons) of dewatered sludge per day. This is due to moisture problems in the sludge resulting in slightly lower solids content than expected. The sludge is trucked to the site from the Blue Plains Sewage Treatment Plant in Washington, D.C.

The plant is located in a densely populated suburb of Washington, D.C. and faced considerable public resistance during site selection. Consequently, the facility is designed and operated with constant attention to neighborhood concerns such as odors, noise, and appearance.

4.4.1 Operations

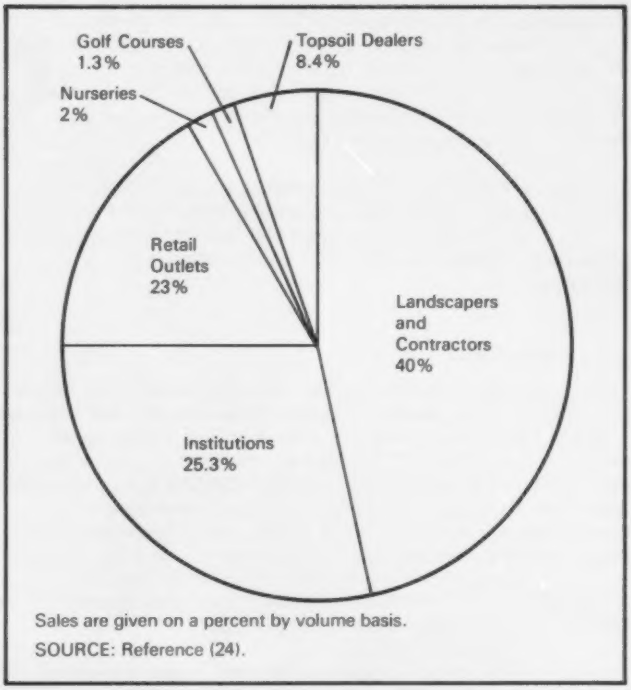
To minimize odors and maintain sludge quality, much of the facility is partially or fully enclosed. The sludge is mixed with wood chips at a ratio of 3.8 m^3 wood chips/wet mt of sludge (4.5 cu yd wood chips/wet ton sludge). [The facility was designed to operate at a ratio of 2 to 2.5 m^3 wood chips/wet mt sludge (2.5 to 3 cu yd wood chips/wet ton sludge), but wetter-than-expected sludge has required the higher ratio. This operational change underscores the importance of sludge moisture content in operations.] The sludge/wood chip mixture is formed into piles 31 m (100 ft) long, 6 m (20 ft) wide, and 3 m (11 ft) tall. A 0.5-m (1.5-ft) thick layer of finished compost is spread on top of the piles.

Fifty-six 11-kilowatt (15-horsepower) blowers provide a maximum aeration rate of 110 to 125 m^3/hr/dry mt of sludge (3,500 to 4,000 cu ft/hr/dry ton). The piles require this maximum rate during the first week of composting to assure aerobic decomposition and minimize odors, and again during the last 2 days of the composting cycle to lower pile temperature and minimize odors prior to screening and curing. A backup generator is available to provide aeration in the event of a power failure.

After the first week of composting, aeration demands of the piles decrease. Pile temperatures are maintained at about 60°C (140°F) for the entire composting cycle except the last 2 days.

Air drawn through the compost piles from the blowers is directed into one central pipe and released into a filter pile of previously composted sludge to trap odorous gases, such as hydrogen sulfide. WSSC personnel are also considering installing a backup chemical odor control system to absorb the hydrogen sulfide.

After composting for 3 weeks, the piles are broken down and screened in a fully enclosed building to minimize dust generation. Approximately 70 percent of the wood chips are recovered during screening. The screened compost is then placed in open-air curing piles. Small blowers maintain aerobic conditions during curing. (Other composting facilities postpone screening until after curing, in which case the lower density provided by the wood chips eliminates the need for blowers during curing. However, some of the wood chips decompose during curing, which reduces recovery rates.)



Sales are given on a percent by volume basis.

SOURCE: Reference (24).

Figure 12. Distribution of ComPRO Sales in 1983 by User Category

4.4.2 Marketing

The composted product is marketed by the Maryland Environmental Service (MES) (a state agency), under the trade name of ComPRO. Suggested uses of the product are as a fertilizer and soil conditioner for alkaline-loving shrubs and trees, for vegetable and flower gardens, and for lawns. ComPRO is also recommended as a component of potting mixes for house plants. At the outset of the marketing program, MES conducted a market survey to determine who would be interested in purchasing composted sludge. MES continues to employ agricultural professionals as sales agents, and to advertise in professional journals and the mass media.

As of late 1983, more than 99 percent of MES's sales were bulk sales (Figure 12). Buyers include landscapers, contractors, universities, military installations, school districts, and a network of about 50 retail outlets in the Washington, D.C., area that in turn sell the product to home owners and other small users. MES sells the compost for \$5.25/m^3 (\$4.00/cu yd) at Site II, but transportation and handling costs raise the retail price to between \$19.60/m^3 and \$39.25/m^3 (\$15.00/cu yd and \$30.00/cu yd).

MES sales of composted sludge from 1981 to mid-1984 totaled about 115,000 m^3 (150,000 cu yd), and were sufficient to handle the volume of compost generated. The revenue generated by sales at the 1984 rate of 46,000 m^3 (60,000 cu yd) per year at Site II are just sufficient to cover the costs of the marketing program.

4.4.3 Costs

The total capital costs for Site II were about \$27 million. Operating and maintenance costs when the site operates at full capacity are expected to average about \$38.50/mt (\$35/ton) of dewatered sludge cake treated (25).

5. Landfilling

5.1 Introduction

Landfilling is a sludge disposal method in which sludge is deposited in a dedicated area, alone or with solid waste, and buried beneath a soil cover. Landfilling is primarily a disposal method, with no attempt to recover nutrients and only occasional attempts to recover energy from the sludge. Currently, about 25 percent of the municipal wastewater sludge generated in the United States is landfilled.

To a certain extent landfilling, like land application, is an extension of sludge treatment. However, there is an important difference. When sludge is landfilled, anaerobic degradation occurs because insufficient oxygen is available for aerobic decomposition, such as occurs during land application and composting. Anaerobic conditions degrade the sludge more slowly and less completely than aerobic processes.

Adherence to proper sanitary landfilling procedures minimizes many potential health, environmental, and aesthetic problems associated with sludge landfilling. However, groundwater contamination by constituents in landfilled sludge remains a concern. Groundwater contamination may be difficult to detect until the damage has occurred, and even if contamination is detected, it may be extremely difficult to correct. Proper planning and site management can help to avoid these problems.

Landfilling has been and continues to be a popular sludge disposal option, but increasing competition for available landfill space has diminished interest in this disposal option. Nevertheless, landfilling can be viable for municipalities that have available land with hydrogeologic characteristics that protect ground water and other drinking water supplies. If landfilling operations are properly planned and executed, a completed landfill site can be sold or used by the municipality for other purposes, such as recreational space. Thus, even if a large area needs to be devoted to filling for several years, it need not be permanent use of the land.

5.2 Process and Performance

Two major types of landfilling are currently practiced:

- *Sludge-only disposal,* in which sludge is buried, usually in trenches.
- *Codisposal,* in which sludge is disposed of at a municipal refuse landfill.

In both cases, adherence to proper sanitary landfill procedures helps to maximize successful performance and minimize potential problems.

5.2.1 Sludge-Only Disposal

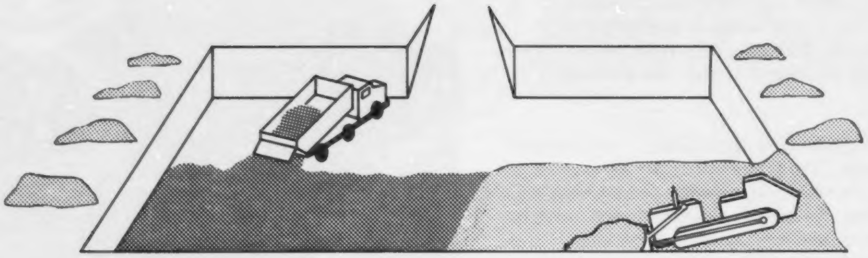
Most sludge-only landfills consist of a series of trenches, dug into the ground, into which dewatered sludge is deposited and then covered with soil. Other sludge-only landfill designs exist (area fill mounds, area fill layers, and diked containment) in which the sludge is deposited on the ground surface, but these are not commonly used. Reference (26) provides further information on all methods.

Dewatered sludge is pumped into a narrow trench from a haul vehicle in Montgomery County, Maryland. Sludge must contain less than 30 percent solids and the trench floor must be nearly level to ensure even spreading of sludge.

Sludge landfill trenches range from 1 to 15 m (3 to 50 ft) in width. At *narrow trenches* [1 to 3 m (3 to 10 ft) wide], dewatered sludge is usually dumped into the trench from a haul vehicle alongside the ditch. The sludge must be less than 30 percent solids and the trench floor must be nearly level to ensure that the sludge will spread evenly throughout the narrow trench. A *wide trench* [3 to 15 m (10 to 50 ft) wide] allows the haul vehicle to work within the trench itself (Figure 13). In this case, the sludge should be at least 30 percent solids (this may include bulking material, such as fine sand) to ensure that it will stay in piles and not slump. The addition of a bulking agent is generally not cost effective if sludge solids content is less than about 20 percent. Instead, further dewatering of the sludge should be done at the treatment plant.

The sludge should be covered with soil the same day it is deposited in order to minimize odors and to prevent insects, birds, and other vectors from contacting the sludge and spreading contaminants. As each new trench is dug, the excavated soil can be used to cover the sludge in a nearby trench. If the sludge is solid enough to support a vehicle (greater than about 30 percent solids), soil cover can be applied by a track dozer within the trench. For sludges less than about 30 percent solids, cover must be applied by a front-end loader or dragline next to the ditch.

Sludges must contain at least 20 percent solids in order to support cover material. Narrow trenches can handle sludges down to 15 percent solids because the ground on either side helps support the cover. Table 10 summarizes sludge characteristics related to different methods of landfilling.



The sludge haul vehicle is working within the trench. The bulldozer is spreading excavated soil as a cover over the deposited sludge layer.

Figure 13. Wide Trench Landfill

Table 10. Sludge Characteristics for Landfilling

	Solids content	Bulking agent required?	Stabilization recommended?
Trench			
Narrow trench	15 - 28%	No	Yes
Wide trench	≥30%	No	Yes
Codisposal			
Sludge / refuse mixture	≥3%	Occasionally	Yes
Sludge / soil cover	≥20%	Occasionally	Yes

Narrow trenches are relatively land intensive. Sludge applications range from about 460 to 2,120 dry metric tons per hectare (dry mt/ha) [200 to 940 tons per acre (tons/ac)] including areas between trenches. Wide trench operations are less land-intensive than narrow trenches, with sludge applications ranging from about 1,200 to 5,480 dry mt/ha (530 to 2,440 tons/ac).

5.2.2 Codisposal

In codisposal, wastewater sludge is deposited in a landfill together with municipal solid waste. In this way, the absorption characteristics of the solid waste and soil conditioning characteristics of the sludge can complement each other. The solid waste absorbs excess moisture from sludge and reduces leachate migration. Sludge can also aid revegetation of the completed codisposal site. The two categories of codisposal are:

- *Sludge/refuse mixture*, in which sludge is deposited on top of refuse and then mixed in.
- *Sludge/soil mixture*, in which sludge and soil are mixed and spread on top of refuse.

Sludge / Refuse Mixture

Most sludge/refuse operations use sludges with at least 20 percent solids, although sludges as low as 3 percent solids have been codisposed by spraying the sludge on the refuse from a tank truck. However, low-solids sludge requires large refuse volumes—as much as 7 tons of refuse for every wet ton of sludge sprayed. The excess moisture in low-solids sludge increases the rate of solid waste decomposition; however, it also increases the likelihood of leachate and methane formation, and is therefore not a recommended method of operation.

Dewatered sludge being mixed with refuse at a codisposal landfill.

The liquid nature of sludge makes sludge/refuse codisposal operations prone to operational problems, including a tendency for the sludge to flow away from the working area and for equipment to slip and stick in the sludge. Long periods of wet weather compound these problems. These difficulties are minimized by depositing only as much sludge as the refuse can handle.

The amount of sludge that can be disposed of at a sludge/refuse codisposal site is low compared to other landfilling processes but high compared to agricultural land application of sludge. It ranges from 180 to 1,600 dry mt/ha (80 to 700 tons/ac). The rate of sludge disposal that a solid waste landfill can handle depends on the rate of refuse delivery and the solids content of the sludge.

Sludge / Soil Mixture

Spreading a sludge/soil mixture over completed refuse fill areas promotes revegetation of the site. (See subsection 3.2.6 for further discussion.) Use of well-stabilized sludges reduces odors that could result if sludge is not completely buried. Sludge/soil covering operations have high manpower and equipment requirements.

Advantages and Disadvantages

Advantages of codisposal include:

- *Shorter time delay.* Permits to allow sludge disposal at an existing refuse landfill are usually processed more quickly than permits for a sludge-only site. Also, because most or all the site preparation required for sludge disposal has been completed, construction delays are unlikely.
- *Lower costs.* Due to the economy of scale, the cost of one codisposal site will probably be lower than the combined costs of two separate sites.

Disadvantages of codisposal include:

- *Malodor.* Odors may be greater than at a solid waste landfill, depending on sludge stabilization.
- *Operational problems.* Because of the relatively liquid nature of sludge and the need to coordinate its disposal with that of refuse, operations become more difficult. When public access to refuse disposal areas is allowed, codisposal operations may not be possible.
- *Unpredictable site capacity.* Wet weather can decrease the bulking capacity of solid wastes and thus decrease the capacity of the site for sludge.
- *Leachate.* Organic acids, formed during the anaerobic decomposition of the landfilled sludge, could enhance the leaching of metals from the solid waste/sludge mixture. Therefore, leachate collection and treatment systems may have to be installed, enlarged, or upgraded to handle increased leachate quantity.
- *Sludge storage.* In some cases sludge may be delivered around the clock, whereas refuse delivery may be confined to certain hours. In such situations, on-site storage may be needed for sludge until sufficient refuse for bulking has been delivered. This procedure necessitates an additional sludge handling step.

Table 11. Range of Constituent Concentrations in Leachate from Sludge Landfills

Constituent	Concentration[a]
Chloride	20 - 600
SO_4	1 - 430
Total organic carbon	100 - 15,000
Chemical oxygen demand	100 - 24,000
Calcium	10 - 2,100
Cadmium	0.001 - 0.2
Chromium	0.01 - 50[b]
Zinc	0.01 - 36
Mercury	0.0002 - 0.0011
Copper	0.02 - 37
Iron	10 - 350
Lead	0.1 - 10[b]
TKN[c]	100 - 3,600
Fecal coliform	2,400 - 24,000 MPN / 100 ml[d]
Fecal streptococcus	2,100 - 240,000 MPN / 100 ml[d]

[a] Concentration is in milligrams per liter unless otherwise noted.

[b] The maximum concentrations shown exceed the limits specified in 40 CFR 261.24 Table I. These limits define hazardous wastes under RCRA.

[c] Total Kjeldahl nitrogen.

[d] MPN / 100 ml = Most Probable Number / 100 ml.

SOURCE: Reference (26).

5.2.3 Leachate

Leachate is generated from the excess moisture in the sludge, usually with some contribution from rainfall. The type and amount of constituents in leachate from a sludge landfill depend on the nature of the sludge. Table 11 gives the range of constituent concentrations in leachate from several study sites.

If landfill leachate reaches an aquifer, heavy metals and toxic organic chemicals are of particular concern because of their possible adverse health effects. If leachate enters surface waters, the resultant elevated nutrient levels can cause eutrophication and concomitant undesirable algal blooms and fish kills. Pathogen contamination of drinking water supplies could also have adverse health effects.

The potential for groundwater contamination can be reduced by properly covering landfills and installing liners to contain any leachate within the fill area and to attenuate harmful contaminants. The majority of states (72 percent) require or can require that soil-based liners, synthetic liners, or both be installed in a sludge landfill (5).

A leachate collection system should be installed in any landfill where leachate is being contained or where water tends to pond in the fill area. The two types of collection systems are:

- A *sump* into which leachate collects and is subsequently pumped to a holding tank or pond.

- A series of *drain pipes* or *tiles* that intercept and channel the leachate to the surface or to a sump. (See Figure 14 for an example.)

5.2.4 Surface Water Containment

All upland drainage should be directed away from the landfill. Working areas of the landfill should have a grade greater than 2 percent to promote runoff and prevent ponding, but less than 5 percent to reduce flow velocities and minimize erosion. Straw bales, berms, or vegetation can be used to reduce flow velocities. Siltation ponds will probably be necessary to settle the solids contained in the site runoff.

5.2.5 Gas Control

The decomposition of organic matter in sludge and solid waste produces methane and other gases, including trace amounts of hydrogen sulfide. Methane is the gas of primary concern. It can seep by diffusion through sludge and other materials into nearby buildings or underground structures, such as utility tunnels, where it may accumulate to explosive concentrations (5 to 15 percent). To prevent this hazard, systems to collect gases are usually installed in landfills located near buildings or underground structures (Figure 15). Reference (26) contains details on gas control methods.

Collected gas can be vented to the atmosphere or incinerated. A third option is to recover and use the methane as an energy source. This is being done successfully at a growing number of solid waste sanitary landfills. However, the minimum landfill size required for economical gas recovery ranges from about 11 ha (28 ac) for a site with a 45-m (150-ft) fill depth to 31 ha (78 ac) for a site with a 15-m (50-ft) fill depth (27). Thus, gas recovery is presently not practiced at sludge-only landfills because they are normally much smaller.

5.2.6 Monitoring

Approximately 60 percent of the states require landfill operators to perform some form of monitoring and keep some form of records (5).

Ground Water

Groundwater monitoring is important if the landfill is located in the vicinity of an aquifer that is a potential drinking water source. Ground water travels slowly along a gradient. Wells located upgradient provide samples of water unaffected by landfill leachate. Wells downgradient from the landfill are used to detect leachate migration from the fill area. A hydrogeologist should assist in designing a groundwater monitoring program. Monitoring should begin 6 months to a year before any landfilling to establish background groundwater quality, including seasonal fluctuations. Once the facility is in operation, an ongoing monitoring program should be established. The frequency of sampling and the parameters analyzed depend on state regulatory requirements and site-specific characteristics. For example, if the local ground water is potable, parameters that have drinking water standards should be measured.

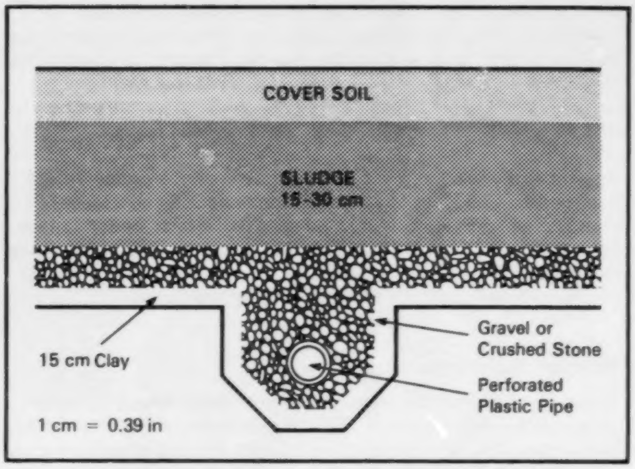


Figure 14. Underdrain for Leachate Collection at a Landfill

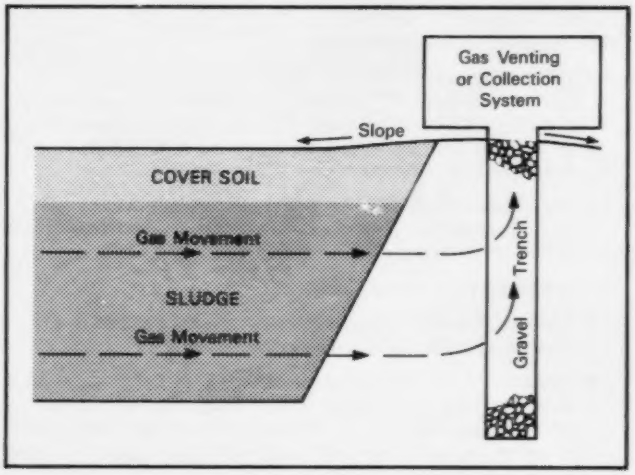


Figure 15. Permeable Method of Gas Migration Control

Surface Water

A surface water monitoring program is necessary if surface runoff or a leachate release could contaminate nearby water bodies.

Gas

If buildings or underground structures are located on or near the site, periodic gas monitoring should be performed to detect methane migration and accumulation.

5.2.7 Contingency and Mitigation Plans

Because of their reliability, landfills are often essential elements of contingency plans for other use/disposal options. However, landfill operations themselves may be disrupted for several hours to several weeks because of vehicular accidents, inclement weather, or labor strikes. To prepare for such emergencies, the wastewater treatment plant should have sludge storage facilities that can accommodate sludge production until landfill operations resume. It is also desirable, although not always feasible, to have a backup sludge use/disposal system.

Another type of emergency that can occur at a landfill operation is a leachate release that threatens ground water or surface waters. A mitigation plan should be prepared that specifies the actions to be taken in the event of such a release—for example, pumping downstream wells to contain the leachate, and treating the extracted water prior to discharge. A plan of action should also be in place in the event methane is detected inside a structure.

5.2.8 Site Closure

After a landfill site is completed, it may be used for various other purposes. Such uses should be planned during site selection. Every step of the landfill process—initial site preparation, installation of screens and buffers, placement of the final landfill cover, and revegetation—should be steps towards achieving the final use. These preparatory steps enhance the ultimate value of the site and reduce redevelopment costs.

Proper site closure procedures should be followed when closing a site or a segment of the landfill (26). After closure, the site should be inspected at monthly to quarterly intervals for several years.

5.3 Key Parameters

5.3.1 Sludge Treatment Requirements

Reference (26) presents guidance on the suitability of various sludges for landfilling. Sludges should be *stabilized* to preclude odor problems and faciliate handling. Almost half of all states require sludge stabilization prior to landfilling (5).

Sludge *dewatering* is an important step prior to landfilling to reduce the potential for leachate formation and to reduce sludge volume. Dewatering is essential prior to sludge-only disposal, where there is no refuse for bulking and where the sludge must support a soil cover. Half of all states require that sludge be dewatered prior to landfilling (5).

5.3.2 Community Size

Landfilling can be successfully practiced by communities of all sizes, if appropriate disposal sites are within economical hauling distance.

5.3.3 Land Requirements

Landfilling can require substantial amounts of land. For example, a municipality generating 25 dry mt (28 dry tons) of sludge per day (i.e., population of about 230,000) will require approximately 2 to 20 ha (4 to 50 ac) of land per year for sludge-only landfilling, depending on trench width, fill area depth, and sludge solids content. This range is important because the areas suitable for landfilling are limited by land use concerns in the community. Finding and gaining access to an adequate landfill site capacity is often the most significant problem in implementing a sludge landfill operation.

Amount of Land

A landfill has a finite size and therefore a finite operating life. This operating life must be long enough to justify purchase, site preparation, and other capital costs, which become less significant when amortized over time.

A landfill's lifespan can be estimated by dividing the volume of sludge it can hold by the volume of sludge landfilled each year. Landfill capacity is the product of the usable fill area (generally 50 to 70 percent of the total site surface area) times the depth of the landfill. The remaining 30 to 50 percent of the site is used for buffer zones, access roads, and soil stockpiles. In calculating landfill size requirements, the projected increase in sludge volume during the lifetime of the site must be considered. This will be a function of community growth and the construction of additional wastewater treatment capacity.

Soil Availability

Soil is often used to increase the solids content of a sludge and to provide interim and final cover. Bulking and cover soil may be present on site, and may be readily available from trench excavation. If sufficient soil is not available on site, or if its physical and chemical properties are not suitable, soil may have to be hauled to the landfill, a costly procedure.

Hydrogeology

Pollution of ground and surface waters are the major environmental concerns associated with sludge landfilling. The depth to ground water, the type of bedrock, and the soil environment affect the potential for groundwater contamination. Any currently used or potentially potable ground water should be protected from landfill leachate.

Site Preparation

The time and cost necessary to prepare a site for landfilling can influence the desirability of that site. For example, a highly vegetated area may require extensive logging or clearing, which can greatly increase capital costs. Varied terrain will increase the cost of constructing sludge haul roads, while a site with an appropriate slope (2 to 5 percent) will help to keep capital costs down by minimizing the need for grading. Varied terrain can, however, offer deep fills to increase site capacity.

Site Access

The physical adequacy of public roadways for truck traffic; the number of residences, parks, and schools fronting the roads; and the effect of traffic congestion must be considered when evaluating the landfill alternative.

5.3.4 Storage

Storage space to accommodate at least several days' or more production of sludge should be provided at the treatment plant and elsewhere in case transportation or labor problems prevent hauling sludge to the landfill site. On-site storage is also desirable in case inclement weather or other problems disrupt site operations. These disruptions can be minimized if special fill areas close to the landfill entrance are designated for use only during inclement weather.

5.3.5 Good Practices

Proper sanitary landfill site planning and management procedures will minimize the potential for leachate formation and migration; methane generation; and surface runoff, erosion, and siltation.

5.3.6 Sludge Quality

The physical characteristics of sludge are important for landfilling. Sludges should be stabilized, dewatered, and mixed with bulking agents to facilitate handling. The chemical composition of sludge is rarely a concern. Sludge chemical characteristics are important only if the sludges are classified as hazardous under the provisions of RCRA. For this reason, sludges that are too highly contaminated for other use/disposal options, but not contaminated enough to be classified as hazardous, may be landfilled.

5.3.7 Public Acceptance

Public acceptance is a key factor in implementing a sludge landfilling operation. Public concerns over landfilling generally focus on potential odors, land values in the neighborhood, increased traffic, and the potential for groundwater contamination. The closer the landfill is to residential or commercial areas, the greater will be the level of public concern. To mitigate public concerns, residents should be involved in the siting, planning, and design of the landfill. The bulk of *public involvement* should be at the beginning of the planning process. Although early input may cause some project delays, it will help minimize public opposition in later planning stages which can be both lengthy and expensive.

The importance of public acceptance of landfilling may be particularly critical if a community must periodically develop new landfill sites. In that case, public acceptance will be an ongoing issue.

Figure 16 illustrates several basic design features that can help gain public acceptance. The fill areas avoid the stream and pond. Groundwater and surface water monitoring stations are in place, and gas control/venting trenches protect the on-site building. Woods visually shield the landfill from the road, railroad, and local residences, and buffer other nuisance effects, such as dust, noise, and odor. The prevailing winds also tend to blow any odors away from the road and inhabited areas.

5.3.8 Transportation Requirements

Transportation of sludge from the treatment plant to the site must be considered from both an economic and a practical standpoint. The costs of sludge hauling can be a major contributor to the costs of landfill operations.

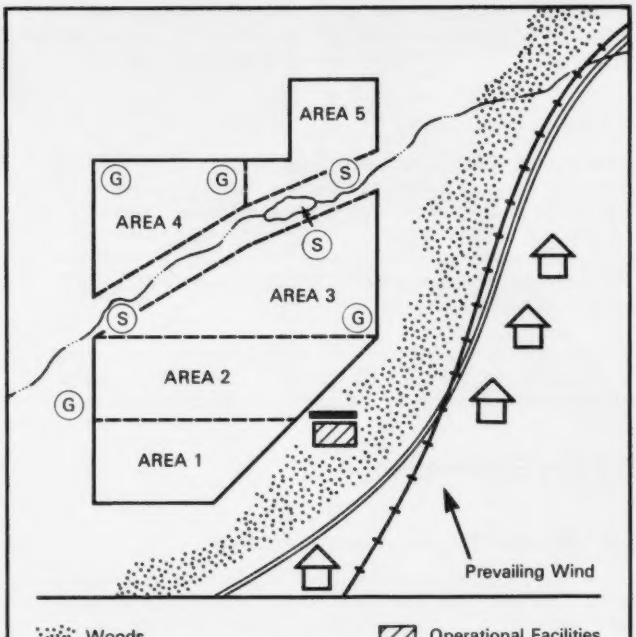


Figure 16. Schematic of a Typical Landfill Site in Relation to the Surrounding Environment

Transport vehicles should be leakproof and should be able to dump sludge easily. Large, enclosed vehicles, such as concrete mixers, have been used. Specialized trucks may not be needed; often, municipalities already have adequate vehicles for sludge transport within their existing fleet.

The most appropriate *transportation route* should be considered from the standpoint of traffic congestion and public acceptability. In addition, the public roads along the route must be able to accommodate the weight and number of trucks required.

5.3.9 Energy Usage

The primary energy inputs into landfilling are fuel for sludge transport from the treatment plant to the landfill site, for the heavy equipment used in landfilling and, if necessary, for operation of dewatering equipment.

5.3.10 State and Federal Regulatory Approval

The same general Federal regulations that govern land application of sludge (see Chapter 3) also govern sludge landfills. State regulations for sludge landfilling are more specific. Some states, such as Minnesota and Vermont, openly discourage sludge landfills, while New Jersey is considering a ban on the option (5).

5.3.11 Cost Factors

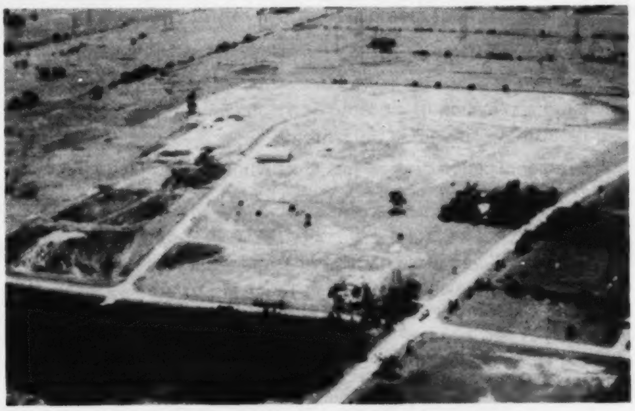
The major *capital costs* associated with sludge landfilling are:

Land acquisition
Site preparation
Equipment purchase.

The major *operating and maintenance costs* are:

Transportation of sludge from the treatment plant to the site: fuel, equipment, maintenance, parts, labor
On-site operations: fuel, equipment, maintenance, parts, labor
Utilities
Laboratory analysis of water samples
Bulking and cover materials.

In general, the dominant costs for landfilling are dewatering and transportation. These costs are interrelated. The drier the sludge, the higher the dewatering costs but the lower the transportation costs. As the haul distance to a landfill increases, the drier the sludge must be for landfilling to be economical.



Aerial view of a sludge-only narrow trench landfill in Lake County, Illinois. Completed, covered cells that are being revegetated with grass can be seen in the upper right. The working area, where new trenches are being dug and filled, is the striated area, center left.

5.4 Case Study

The North Shore Sanitary District (NSSD) of Lake County, Illinois, treats wastewater from 11 municipalities and unincorporated areas (approximately 230,000 people) and two major military bases at three advanced wastewater treatment plants and one pretreatment facility. The advanced treatment plants consist of conventional, primary, and secondary waste-activated sludge systems, followed by biological nitrification and sand filtration. One of the advanced treatment plants has capabilities for anaerobic digestion of sludge.

Sludges from all plants are pumped or hauled to one plant, in Waukegan, where they are conditioned with lime and ferric chloride and dewatered to at least 20 percent solids. The dewatered sludge is then transported 16 km (10 mi) in standard 30-cubic-yard (23-m^3) dump trailers to the sludge-only landfill.

During 1982 to 1983, NSSD treated over 68.9 million m^3 (18.2 billion gal) of wastewater (about 20 percent industrial effluent), producing 136,000 m^3 (36 mil gal) of liquid sludge. Of that, 128,700 m^3 (34 mil gal) were dewatered, producing over 36,000 wet mt (40,000 wet tons) or about 9,000 dry mt (10,000 dry tons) of sludge. The dewatered sludge was transported in 2,700 trailer trips to the landfill. The remaining 7,600 m^3 (2 mil gal) was digested sludge that was not dewatered, but was directly injected into surrounding agricultural land.

5.4.1 History

Before the NSSD landfill was implemented, sludge was treated and disposed of in several ways: lagoons, sand drying beds, trucking out of the district for disposal, and land application within Lake County. None were satisfactory long-term solutions.

In the late 1960s, four methods of sludge use/disposal were considered:

- Incineration.
- Land application of digested dewatered sludge on cropland, followed by discing or plowing.
- Land application of digested liquid sludge on cropland by irrigation.
- Landfilling.

On the basis of cost evaluation studies and what was environmentally acceptable to local and state governments, landfilling appeared to be the best alternative. Incineration was ruled out, in part because of concern about how stringent the ultimate air quality standards would be. Expanding the land application program was not feasible.

Potential landfill sites were selected on the basis of short-haul distances of about 15 km (10 mi) from the dewatering facility, availability of land for purchase, and greatest public acceptance.

The final site selected was 114 ha (282 ac) with 81 ha (200 ac) suitable for landfill operations. The soils consisted of 0.5 m (2 ft) of topsoil, followed by 6 to 7.5 m (20 to 25 ft) of silty clays, and finally 2 to 4.5 m (6 to 15 ft) of tight, blue clays. NSSD, its consultants, the Lake County Soil and Water Conservation District, and the U.S. Department of Agriculture's Soil Conservation Service developed a plan for site preparation and use that met the requirements of the State of Illinois "Rules and Regulations to Refuse Disposal Sites and Facilities." In addition, the plan included the following requirements:

- Maintain a 45-m (150-ft) buffer between sludge deposits and adjacent residential properties or state highway.
- Landfill only dewatered sludge conditioned with lime and ferric chloride.
- Install 10 groundwater monitoring wells at state-approved locations, and monitor for 22 contaminants annually and 5 contaminants quarterly.
- Install gas monitoring wells at state-approved locations, and monitor for methane, carbon dioxide, and oxygen.

Other design considerations included:

- Relatively low-solids sludge (20 percent).
- Adequate protection of the existing, potable aquifer.
- Soil stability for trenching operations.
- Maximum use of the site acreage.

There were no major public acceptance problems. People living near the landfill site were apprehensive when the project began. Because of the control and care taken by the NSSD with regard to safety, odor control, and appearance, these fears were virtually eliminated.

5.4.2 Landfill Operation

The NSSD landfill consists of a series of trenches, each about 4.5 m wide and 245 m long (15 ft by 800 ft). Each trench is dug with a backhoe and filled in sections, called cells, that are 15 to 55 m (50 to 180 ft) in length. A minimum of 3 m (10 ft) of impervious clay is maintained between the bottom of a trench and any continous water-bearing strata.

During fill operations, temporary protective berms built from excavated trench material (trench spoil) prevent surface runoff from entering the cells. A final 1.5-m (5-ft) layer of soil covers each cell. When a fill area is complete, the area is graded and grassed. If a cell settles after a few years, additional soil is added and the area regrassed.

Sludge is generally deposited in 0.5-m (2-ft) layers and covered with 0.3 m (1 ft) of trench spoil. Although the percent solids is maintained above 20 percent, small variations in sludge consistency cause large changes in its ability to support cover. Because of this phenomenon, the depth of sludge and the quantity of spoil used to cover it become critical, and those are left to the judgment of the site operator. To date, monitoring has not detected any contamination of ground water in on-site wells.

5.4.3 Costs

The annual costs for NSSD landfill operations, based on fiscal year 1982-1983 and a sludge production rate of about 9,000 dry mt/yr (10,000 dry tons/yr), are summarized in Table 12.

5.4.4 The Future

The landfill was started in 1974 with an anticipated lifespan of 20 years. In mid-1984, the capacity of the site was about half used and the initial estimate of lifespan appeared to be correct.

The NSSD is considering several options for land use after site closure, including:

- Silviculture. For example, hybrid poplars could be grown to provide wood chips for possible future sludge composting programs.
- Recreational facilities, such as a park, golf course, or forest preserve area.
- Agriculture.

Although the landfill site still has about 10 years of operation, future sludge use/disposal options are under investigation. NSSD's options include:

- Continuing present landfilling practice.
- Initiating projects such as:
  - expanded use of liquid sludge
  - pilot sludge cake surface incorporation
  - pilot compost operations.

Table 12. North Shore Sanitary District Costs for Fiscal Year 1982/83

Summary:

	$/dry mt	$/dry ton
Dewatering	$100.66	$ 91.50
Hauling	53.08	48.25
Landfill capital	5.45	4.95
Landfill O&M	57.10	51.91
Total	$216.29	$196.61

Dewatering sludge:

	$/dry mt	$/dry ton
Labor	$ 32.42	$ 29.47
Chemicals	25.01	22.74
Allocated overhead	21.87	19.88
Supplies	11.28	10.25
Depreciation	5.84	5.31
Electricity	2.32	2.11
Fuel	1.83	1.66
Misc. direct costs	0.09	0.08
Total	$100.66	$ 91.50

Hauling dewatered sludge:

	$/dry mt	$/dry ton
Labor	$ 32.62	$ 29.65
Allocated overhead	15.02	13.65
Transportation	4.42	4.02
Supplies	0.66	0.60
Depreciation	0.35	0.32
Misc. direct costs	0.01	0.01
Total	$ 53.08	$ 48.25

Landfill capital[a]:

	$/dry mt	$/dry ton
Land	$ 2.48	$ 2.25
Site preparation	1.80	1.64
Monitoring wells	1.17	1.06
Total	$ 5.45	$ 4.95

Landfill O&M:

	$/dry mt	$/dry ton
Allocated overhead	$ 14.37	$ 13.06
Labor	13.52	12.29
Vehicles & fuel	10.71	9.74
Materials & supplies	7.25	6.59
Depreciation[b]	5.32	4.84
Maintenance	2.62	2.38
Equipment rental & services	2.56	2.33
Utilities	0.73	0.66
Miscellaneous	0.02	0.02
Total	$ 57.10	$ 51.91

[a] Initial capital expenditures are divided by the total amount of sludge received over the life of the site.

[b] Equipment costs were depreciated on a straight-line basis for 10 years for heavy equipment and 6 years for automotive.

[c] SOURCE: Reference (28).

Economically, the NSSD's present practice of landfilling dewatered sludge remains their most cost-effective use/disposal method. However, at the time the NSSD acquired the landfill site, the average cost of land was $4,940/ha ($2,000/ac). A recent survey of available land indicated costs of $14,820 to $24,700/ha ($6,000 to $10,000/ac). If landfilling continued to be their sludge disposal option, an additional 185 ha (460 ac) would have to be purchased in 1990 at a projected cost of $3,722,000. Thus the availability of suitable land at a reasonable cost would be an important factor.

Further information on this case history is available in reference (28).

6. Incineration

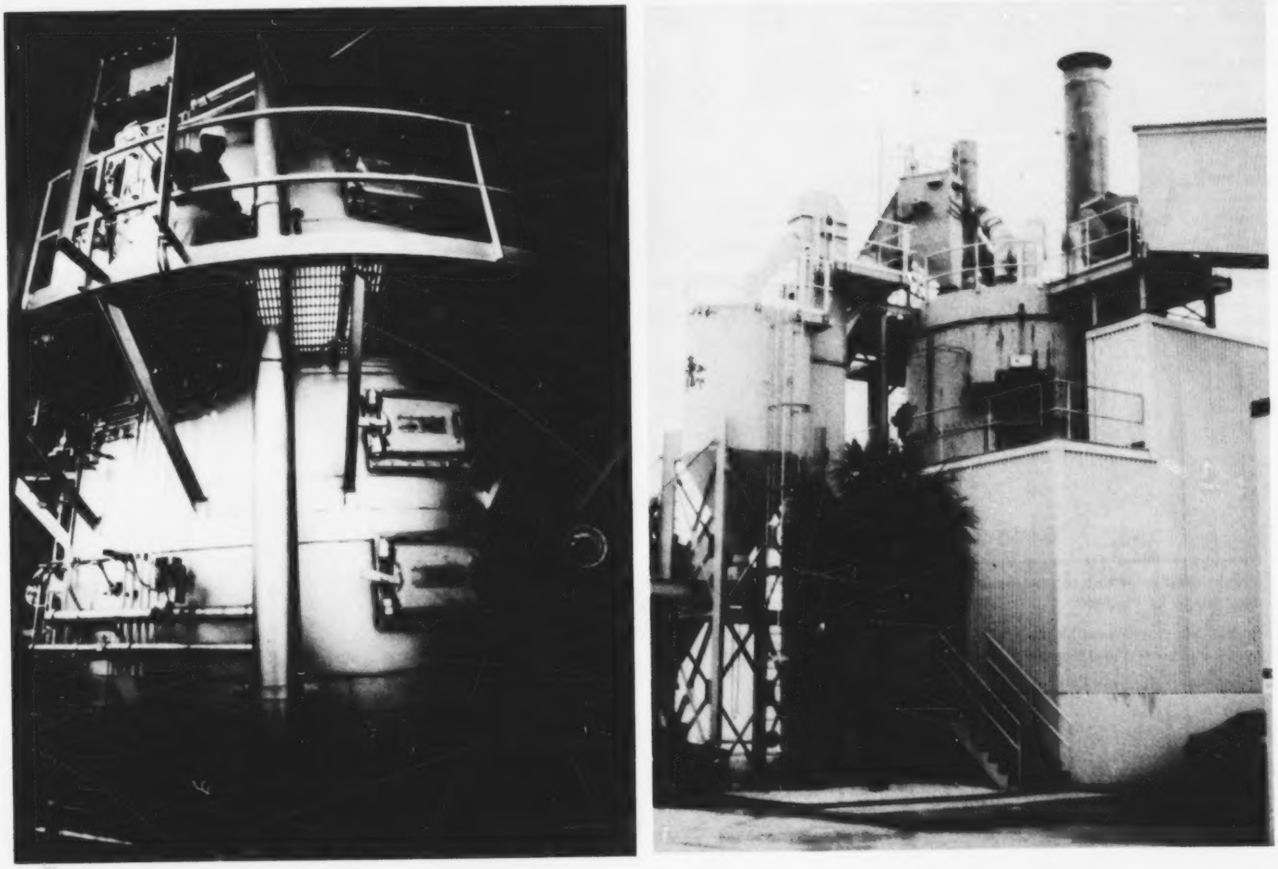
6.1 Introduction

6.1.1 What Is Incineration?

Incineration is the burning of volatile materials in sludge solids in the presence of oxygen. Strictly speaking, incineration is not a sludge disposal or use method, but a treatment method that converts sludge into an ash, which is then disposed of or used. Nevertheless, because incineration drastically reduces the volume and mass of residual solid materials, it has traditionally been regarded as a disposal method, and is evaluated alongside land application, distribution and marketing, landfilling, and ocean disposal as a use/disposal option. Additional information on sludge incinerator design can be found in reference (4).

Other thermal processes for the destruction or treatment of sludge exist, but only incineration is in wide use today. Starved-air combustion—the burning of sludge in insufficient oxygen to completely degrade the sludge constituents—may eventually enable substantial reductions in fuel usage and particulate emissions compared to incineration, but is only now being introduced on a plant scale. Coincineration—the burning of municipal sludge and refuse together—has been employed in full-scale projects but, with few exceptions, has proven impractical. In contrast, incineration is a proven sludge disposal technique, and is currently used on 25 percent of the nation's wastewater sludge (29).

Recent experience with applying the latest in energy recovery technology and efficient operating techniques to wastewater sludge incinerators, including older incinerators, has shown that incineration can be an affordable and competitive sludge disposal alternative under the right circumstances. Details of some of these techniques are included in the case study of Hartford, Connecticut (Section 6.4). Similar experiences in retrofitting older systems as well as in designing new systems are in references (29,30,31).



Wastewater sludge incinerators.

6.1.2 Advantages and Disadvantages

Incineration offers significant advantages over other use/disposal options: it reduces the sludge to a compact residue consisting of about 20 percent of the original volume of the sludge solids, and it eliminates some potential environmental problems by completely destroying pathogens and degrading many toxic organic chemicals. Metals, however, are not degraded, but are concentrated in the ash and in particulate matter entrained in the exhaust gases generated by the process. High-pressure scrubbers or other pollution control devices are needed to prevent degradation of air quality, and appropriate means of ash disposal may occasionally be difficult to find.

A major potential problem with all incineration systems is operational reliability. Because incineration is much more highly mechanized than other sludge use/disposal alternatives, it is particularly subject to varying sludge quality and quantity, equipment failure, and operator error. Inconsistent quality of sludge feed, poor maintenance, and insufficient operator training can greatly increase the frequency of these problems and, consequently, the expense of sludge incineration. Although many municipalities are successfully operating sludge furnaces, many others have had to shut down operations due to repeated equipment breakdowns and operating costs much higher than originally predicted.

Municipalities that may wish to consider incineration include those where:

- Surrounding land is unsuited to landfilling or land application.
- There is strenuous local opposition to other alternatives.
- State and local regulations impose stringent requirements on other alternatives.
- The sludge contains high levels of pathogens or organic chemicals that interfere with the use or disposal of sludge by other methods.

6.2 Process and Performance

When sludge is burned in incinerators in the presence of sufficient oxygen, the flammable constituents are converted to their basic chemical components (mainly carbon dioxide and water). A conceptual diagram of incineration is provided in Figure 17.

Three factors determine how much energy must be added to the incineration process or, in a few cases, how much excess energy can be recovered from the process. These three factors are the thermal content of the sludge, the amount of excess air (above the theoretical minimum required for combustion) required, and the water content of the sludge. High thermal content, low rates of excess air use, and low percentages of water in the sludge make incineration more energy efficient and economical.

Sludge with a high *thermal content* burns readily with reduced supplementary fuel and requires less dewatering to burn autogenously (i.e., burn by itself with no supplementary fuel). The thermal content of the sludge depends largely on the sources of the wastewater, but can be lowered during treatment by such processes as inorganic chemical conditioning, which adds large quantities of material with no fuel value to the sludge. Sludges containing large amounts of grease or oil generally have a high thermal content; burning such materials has sometimes produced higher temperatures than the incinerator was designed for.

Dry raw sludge solids typically are comparable in fuel value to low-grade coals, wood, and municipal refuse, with typical heat values of 1,700 to 5,000 kiloJoules per dry kg (kJ/dry kg [5,000 to 16,000 British Thermal Units (BTU) per dry lb]). Table 13 compares the heat values of several sludge materials against various fuels. In order to burn without auxiliary fuel, sludge usually must contain 25 to 35 percent solids, a level that is achievable with some sludges through conventional mechanical dewatering.

Conventional sludge incineration systems use 20 to 150 percent *excess air* above the theoretical amount needed because it is virtually impossible to ensure complete and even mixing of air and sludge. In the absence of energy recovery equipment, the heated air exits at high temperatures and represents a significant energy drain on the system. The amount of excess air required is partially a function of the type of system chosen, but is also highly dependent on operating procedures. Well-trained operators and appropriate process controls can significantly lower the amount of excess air required, resulting in reduced costs. For example, decreasing excess air flow from 100 percent to 20 percent can cut the use of auxiliary fuel by almost half.

Nearly all the auxiliary fuel used in incineration goes to evaporate *water* from the sludge. The need for auxiliary fuels can be greatly reduced by efficient dewatering. At 25 to 35 percent solids, most sludges will burn without supplementary fuel.

Table 13. Typical Heat Values for Several Sludge Materials and Various Fuels

Materials	Dry solids combustibles (%)	Heat value kJ/kg dry solids	 BTU/lb dry solids
Sludge material:			
Grease and scum	88.5	5,400	16,700
Raw sludge solids	74.0	3,350	10,285
Digested sludge	59.6	1,720	5,290
Fuels:			
No. 2 oil	–	6,390	19,600
No. 6 oil	–	5,700	17,500
Natural gas	–	7,430	22,800
Bituminous coal	–	4,430	13,600
Wood (air-dried)	–	1,790	5,500
Refuse-derived fuel	–	2,440	7,500

SOURCE: References (32,33).

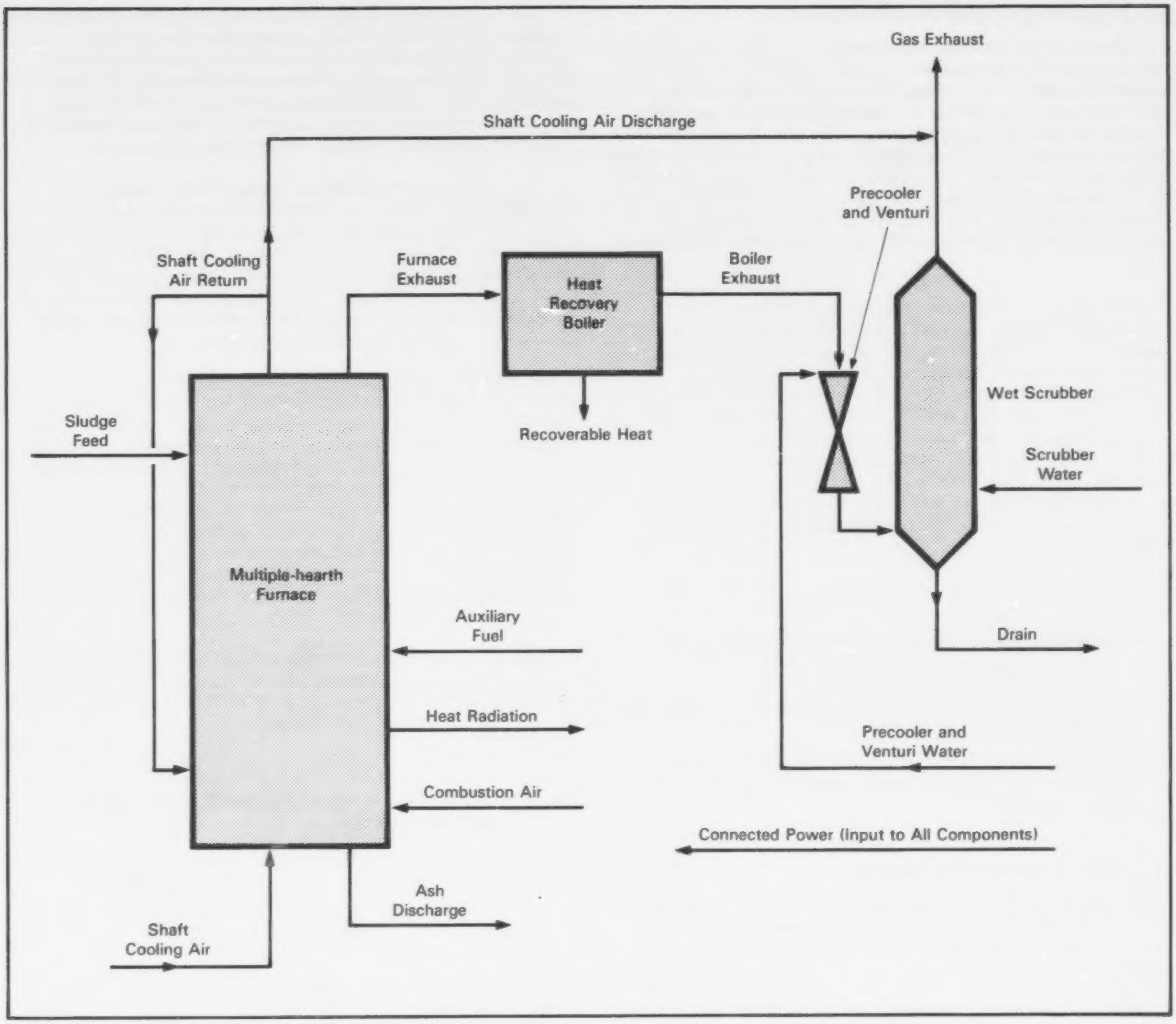

Gas Exhaust
Shaft Cooling Air Discharge
Precooler and Venturi
Shaft Cooling Air Return
Furnace Exhaust
Heat Recovery Boiler
Boiler Exhaust
Wet Scrubber
Sludge Feed
Recoverable Heat
Scrubber Water
Multiple-hearth Furnace
Auxiliary Fuel
Drain
Heat Radiation
Precooler and Venturi Water
Combustion Air
Connected Power (Input to All Components)
Ash Discharge
Shaft Cooling Air

Figure 17. Flowsheet for Multiple-Hearth Sludge Incineration Furnace

The sludge solids content also affects the loading rates of the system, which in turn influences system efficiency. Although dewatering is expensive, it can substantially reduce the overall costs of incineration both by reducing fuel consumption and by reducing the volume of sludge to be burned, thereby reducing the size of the incinerator needed (see Section 6.4). Dewatering also reduces emissions by reducing the amount of excess air used during incineration and by reducing the amount of steam in the exhaust gases. The reduction in excess air usage means that fewer particulates will be entrained. Furthermore, since steam may entrap organic compounds from the sludge and carry them into the exhaust gases, steam reduction reduces the amount of toxic organics present in the off-gases.

There are three basic approaches to removing water from the sludge in incineration systems:

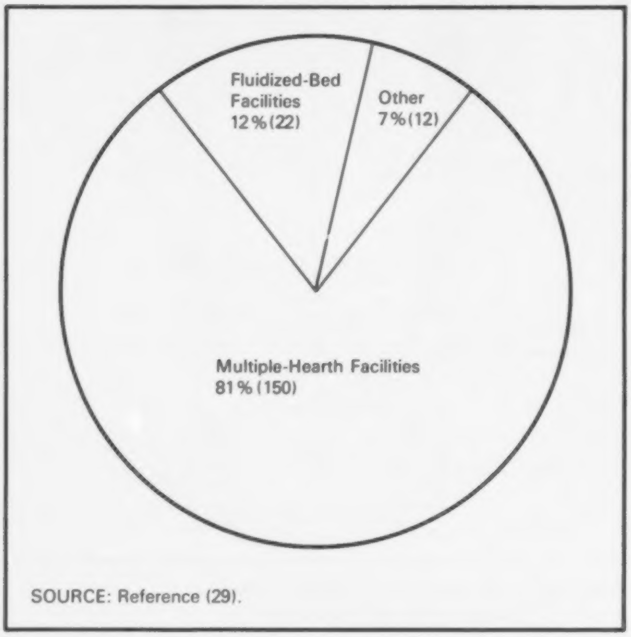
- Chemical and/or thermal conditioning and dewatering before incineration.
- Burning additional fuel during incineration.
- Using heat from exhaust gases to dry incoming sludge or preheat incineration air.

Many types of incinerators have been devcloped, but only two—the multiple-hearth furnace and the fluidized-bed furnace—are widely used in the United States. Other less widely used incineration processes include single-hearth cyclonic furnaces, electric furnaces, and rotary kilns. The relative use of different types of incineration facilities is shown in Figure 18.

6.2.1 Multiple-Hearth Furnace

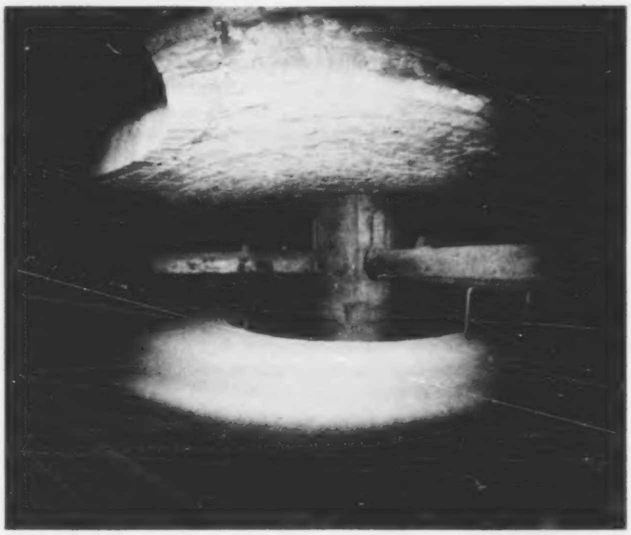
The multiple-hearth furnace (MHF) is the most commonly used sludge incineration system. It is durable, simple to operate, and tolerant of variations in sludge quality and loading rates. The MHF consists of a cylindrical, ceramic-lined steel drum, from 1.4 to 8.8 m (4.5 to 29 ft) in diameter, containing 4 to 14 horizontal hearths (Figure 19).

Sludge enters the furnace near the top and is pushed alternately to the center or the periphery of each hearth, where the sludge drops



SOURCE: Reference (29).

Figure 18. Relative Prevalence (and Numbers) of Sludge Combustion Facilities Operating in the United States



Fish-eye view inside one hearth of a multiple-hearth furnace. Sludge drops into this hearth from the periphery of the hearth above and is shunted by the rabble arms into the center, where it drops down to the hearth below.

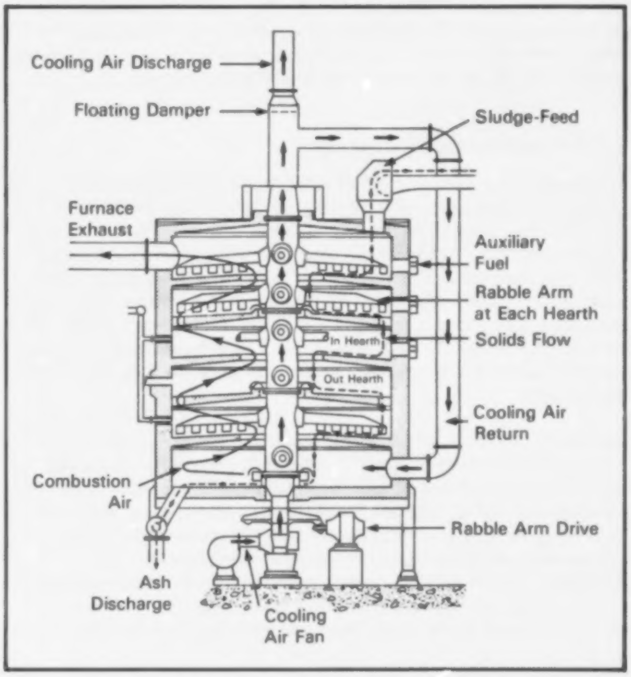

Cooling Air Discharge
Floating Damper
Sludge-Feed
Furnace
Exhaust
Auxiliary
Fuel
Rabble Arm
at Each Hearth
Solids Flow
In Hearth
Out Hearth
Cooling Air
Return
Combustion
Air
Rabble Arm Drive
Ash
Discharge
Cooling
Air Fan

Figure 19. Cross-Section of a Multiple-Hearth Sludge Incineration Furnace

down to the next hearth. Incineration takes place on the middle hearths, where temperatures generally range from 769°C to 816°C (1,400°F to 1,500°F) (4). The hot gases from incineration rise through the upper hearths, drying the incoming sludge before it drops to the hearth where combustion takes place. After incineration, ash is pushed onto still lower hearths where it cools, giving off heat to incoming air.

The MHF has several disadvantages. For instance, to avoid cracking the ceramic lining, MHFs must be heated or cooled very slowly, which makes them impractical for intermittent use. Some communities use the MHF for intermittent sludge flows by burning supplementary fuels during slack times, but this is also costly. Another strategy is to store sludge until enough has accumulated to justify a period of continuous operation, but this requires investment in storage facilities and presents manpower scheduling problems.

Also, because hot exhaust gases are used to dry incoming sludge, they may pick up toxic volatile organics, hydrocarbons, or odorous compounds. The temperature of the exhaust gases at this point is not high enough to destroy these compounds, and they may need to be removed from the exhaust gases prior to release. Gas removal is accomplished with an afterburner, which raises the temperature of the exhaust gases momentarily to 800°C (1,472°F), thus destroying the organic substances. The use of an afterburner can raise fuel and capital costs significantly. Another disadvantage of MHFs is that they usually require more excess air than other incinerators, raising fuel costs still further. This disadvantage can be avoided by careful operation. Under strict operating practices (see Section 6.4) the amount of excess air required can be reduced to as low as 20 percent above the theoretical minimum.

6.2.2 Fluidized-Bed Furnace

The fluidized-bed furnace (FBF) is the other commonly used type of incinerator. Consisting of a vertical, ceramic-lined, steel drum, the FBF contains a sand bed into which air is injected, expanding the bed and reducing its density to the point where it responds as a fluid. The temperature of the bed is maintained at between 769°C and 816°C (1,400°F and 1,500°F). Sludge is fed either directly into the bed or just above it, and ash, some sand, and stack gases exit through the top of the unit (Figure 20). The exhaust gases can be used to indirectly preheat incoming incineration air through a heat exchanger.

Because of the high exit temperature of the gases, odorous compounds and toxic organic compounds are usually destroyed in the incineration chamber, and no afterburner is needed. However, pollution control devices are necessary to remove sand, ash, and heavy metals from the stack gases. Use of too much air blows excess sand and incomplete incineration products into the off-gases. Ordinarily, sand losses from the bed are about 5 percent of bed volume for every 300 hours of operation. The dust content of the untreated stack gases can be as high as 200 grams/m³.

The FBF requires only 20 to 45 percent excess air; thus, for the same exit gas temperature, the FBF is more fuel-efficient than all but the best-run MHFs. Additionally, use of stack gases to preheat the incoming air can lower fuel costs up to 61 percent. The heat storage capacity of the sand bed itself allows for quick startup after relatively short shutdowns (i.e., overnight). Finally, the FBF has approximately three times the incineration capacity of a similarly sized MHF; however, capital cost estimates for the same sludge-burning capacity are comparable. In current practice, the FBF furnaces are more frequently chosen for smaller plants, whereas larger plants use MHFs.

Although the FBF is conceptually simple, contains few moving parts, and is relatively easy to operate, there have been problems with breakdowns of temperature controls, jamming of sludge injection equipment, and sand damage to pollution control devices.

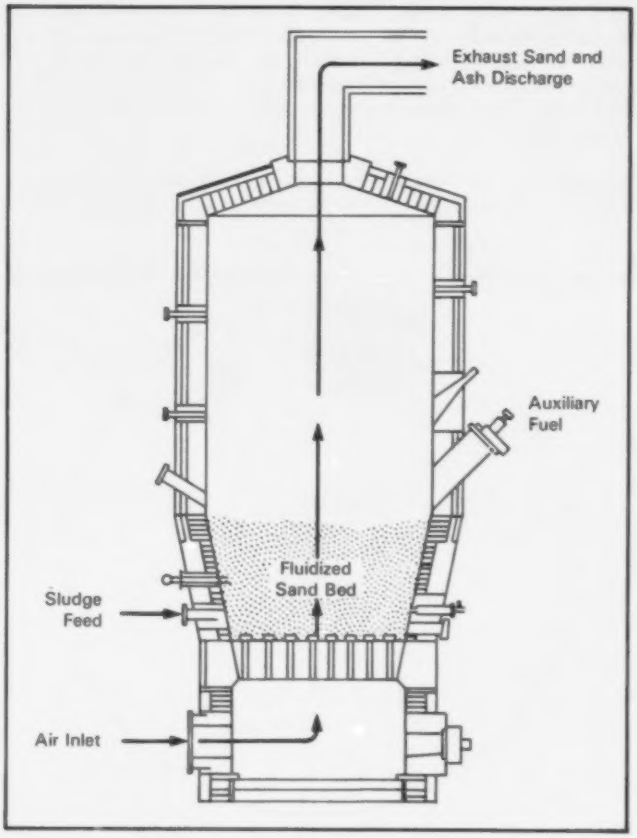


Figure 20. Cross-Section of a Fluidized-Bed Sludge Incineration Furnace

6.2.3 Ash Disposal

Ash disposal is the last step in the incineration process. Because incinerator ash is sanitary, odorless, and free from toxic organic chemicals, its disposal may be less complicated than the disposal of the sludge itself. The ash often contains heavy metals, which are generally immobilized in soils due to the high pH of the ash. In only a few cases has the metal content of the ash caused problems in finding a final disposal site. For example, Salem, Massachusetts, chose to cease incinerating its sludge because of high chromium levels in the wastewater discharges by the large local tanning industry. The chromium was converted to hexavalent chromium during incineration. Ash from this process failed to meet the criteria of the EP test (see Section 2.3) and was required to be treated as a hazardous waste.

Incinerator ash can be applied to land as a soil conditioner, where it can take the place of phosphate and ground limestone supplements. The ash can also provide necessary trace metals to the soil. Other uses of ash, such as addition to soil to improve the freeze-thaw characteristics of road grades or to partially replace sand in cement manufacturing, have been tried on an experimental basis. Ash from some communities has been evaluated as an ore for gold and silver recovery (34).

6.3 Key Parameters

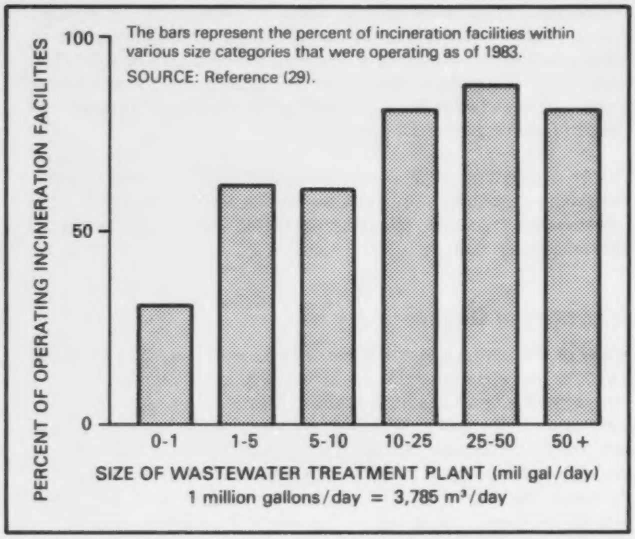
6.3.1 Sludge Treatment Requirements

Because the water content of the sludge is one of the most important factors in determining incineration costs, dewatering is an essential part of modern incineration systems.

Stabilization, however, is unnecessary since incineration destroys pathogens, and is undesirable since it reduces the thermal content of sludge. In some areas the digester gases from stabilization are used as an auxiliary fuel in incineration or in other plant operations, in which case the energy penalty of stabilization is reduced. Stabilization also reduces sludge mass, which reduces the capital cost of the facility and provides a sludge which is easier to dispose of when the incinerator is out of service.

6.3.2 Community Size

Larger municipalities can often absorb the capital costs of incineration systems. Furthermore, because incineration systems are more efficient when operated continually, a large volume of waste is necessary for economical incineration. Some small communities have achieved continuous incineration by storing several weeks' worth of sludge and then burning it in a relatively short period of time; however, larger incineration facilities historically have been more successful than smaller ones (see Figure 21).



The bars represent the percent of incineration facilities within various size categories that were operating as of 1983.

SOURCE: Reference (29).

Figure 21. Success of Incineration by Plant Size

6.3.3 Land Requirements

Very little land is required for the incinerator itself; however, land is required for the ultimate disposal of the incinerator ash. The mass of ash is about 15 or 20 percent that of the dry solids in the original sludge, or higher if inorganics are used in dewatering.

6.3.4 Storage

Incineration is not weather dependent and can be carried out year round, so extensive sludge storage is not required. Often the storage capacity provided by thickening and dewatering steps is sufficient for the entire system. However, since incinerator repairs may take days or weeks if parts are not inventoried, it is essential to have backup storage capacity, a backup incinerator, or an available alternative use/disposal method, if adequate storage is not provided.

6.3.5 Good Practices

Good operating practices are often the key to successful sludge incineration. Perhaps the single most important factor in good practice is thorough *operator training*. An operator who understands the system and knows how to respond to an unexpected situation in the most appropriate manner can prevent damage from excessive temperatures or rapid temperature change, can conserve fuel usage, and can keep pollutant emissions low.

Even highly trained operators, however, will be helpless without *appropriate instrumentation* with which to monitor the situation inside the incinerator. Such instrumentation is not necessarily expensive. By monitoring and manipulating the flow of air and the temperature at different hearths within the incinerator, an operator can optimize system efficiency by controlling where combustion takes place within the furnace. Provision should also be made for *monitoring of stack emissions* from the facility and correlating them to operating variables such as scrubber pressure drop and the oxygen content of the off-gases.

Finally, consistent and conscientious *maintenance* is also crucial to the proper operation of incinerators. In the absence of good maintenance practices, efficiency and effectiveness decline, and operating costs rise.

6.3.6 Sludge Quality

Many of the pathogens and toxic organic chemicals that must be carefully managed when sludge is land applied or landfilled are destroyed during sludge incineration. Metals, such as cadmium and lead, are not destroyed, however, and are associated with the ash and fine particulates in the stack emissions. In modern incinerators, the particulate content of stack emissions can be easily reduced to the levels required by EPA regulations (see subsections 6.3.3 and 6.3.10). However, cadmium and lead tend to be associated with fine particulates, which are not as efficiently removed by the high pressure scrubbers as large particulates (35). Cadmium and lead stack emissions are under continuing regulatory review.

Mercury is another metal that may occur in sludge. It is currently controlled as a hazardous air pollutant because, unlike cadmium and lead, it is considered to be completely volatilized within sludge incinerators.

The metals in sludge incinerator ash are rarely of concern. In a few instances, however, state regulations may require that ashes with a high metal content be treated as a hazardous waste. In these cases the cost of ash disposal may be very high.

6.3.7 Public Acceptance

Gaining public acceptance of sludge incinerators requires assuring adequate air quality impacts and acceptable costs.

6.3.8 Transportation Requirements

If an incineration facility serves several wastewater treatment plants, transportation of sludge to the facility may be an important factor. Provisions must be made for the additional traffic from these transfers.

If the incineration facility is located at the wastewater treatment plant, as is often the case, transportation requirements will be limited to transporting the ash for land application or landfilling.

6.3.9 Energy Usage

Fuel usage is generally the primary operating cost of an incineration system. The amount needed depends on the water content of the sludge, the efficiency of the particular system, volatile sludge solids content, the cost of fuel, and operator skill. Energy is required in every step of the incineration process:

- Sludge dewatering prior to incineration.
- Auxiliary fuel during incineration.
- Heating of incineration air prior to use.
- Operation of air pollution control equipment.
- Transportation of sludge to the facility and ash to an ultimate disposal site.

Electrical requirements for incinerators vary between 14,000 and 90,000 kilowatthours (kWh) per dry ton of daily capacity. The lower amount is for a multiple-hearth unit, and the higher amount for a fluidized-bed incinerator.

Fuel requirements for sludges containing 20 percent solids are about 13.7×10^3mJ (13 million BTU), or about 341 l (90 gal) of fuel oil.

6.3.10 State and Federal Regulatory Approval

Incineration of municipal sludge is regulated under the Clean Air Act (CAA). The cornerstone of the act is a set of National Ambient Air Quality Standards (NAAQS) for specific pollutants. The CAA also specifies particular technological requirements that must be met regardless of whether emission controls are necessary to meet specific air quality standards.

There are national ambient air quality standards for six pollutants:

- Ozone
- Total suspended particulates
- Sulfur oxides
- Lead
- Nitrogen dioxide
- Carbon monoxide.

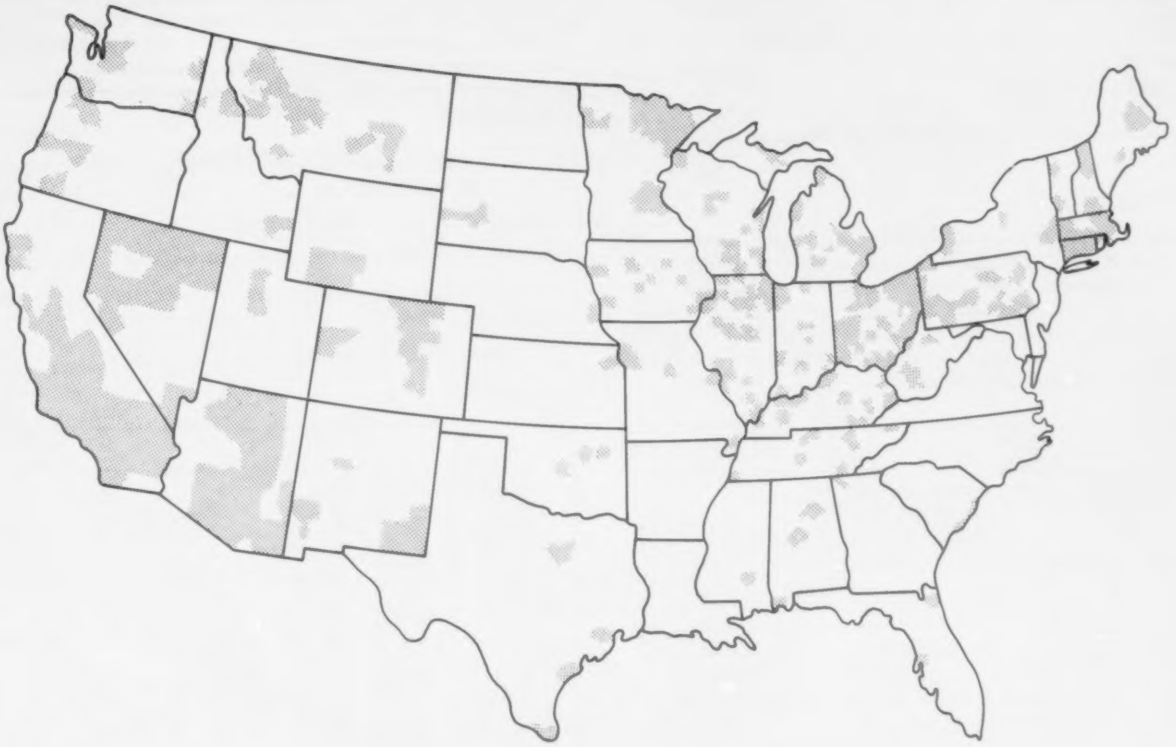
Parts of the country that do not meet one or more of these standards are designated as nonattainment areas. Sludge incinerators contribute primarily to ambient particulate loadings. Figure 22 shows the locations of nonattainment areas for particulates as of 1982.

Before a new incinerator can be built in a nonattainment area, emissions offsets greater than or equal to the increment in emissions that the new incinerator would cause must be demonstrated. Often these offsets can be found on site. For example, a major wastewater treatment facility in Los Angeles was able to acquire sufficient offsets simply by replacing diesel engines located on site with lower emission turbines.

Incinerators constructed or significantly modified since June 11, 1973, are subject to additional regulation under the New Source Performance Standards, which limit discharge of particulates to 0.65 g/kg (1.30 lb/ton) dry sludge input (Subpart O, 40 CFR 60). These standards apply to any incinerator that burns more than 10 percent wastewater sludge at a rate greater than 1,000 kg (2,205 lb) per day. Usually incinerators will have to use high pressure scrubbers to meet these requirements, but some incinerators have been able to meet the standard solely through strict operating practices.

The emission of mercury and beryllium from sludge incinerators and drying equipment is regulated under 40 CFR 61. However, this regulation rarely causes concern, since most sludges have low concentrations of these elements.

State Implementation Plans may require a facility to demonstrate that air quality impacts will be within acceptable levels. To accomplish this, mathematical models may be used to predict emission levels.



SOURCE: Reference (36).

Figure 22. Designated Nonattainment Areas (Counties and Portions of Counties) for Total Suspended Particulates as of 1982

6.3.11 Cost Factors

The costs of sludge incineration are frequently higher than for other use/disposal options. Capital, labor, and energy costs are all often high and may be unpredictable. High capital costs are due to the necessity for complex facilities capable of operating reliably at extremely high temperatures. Labor costs for system operation and maintenance may also be relatively high due to the need for skilled personnel.

The major *capital costs* for incineration are:

Dewatering equipment
Incinerator
Pollution control equipment
Fuel storage facility.

The major *operating and maintenance costs* are:

Labor
Fuel
Replacement mechanical equipment, duct work, and fire bricks
Electric power (for dewatering operations and incinerator mechanical power)
Transportation (for ash transport)
Landfilling or land application (for ash disposal).

6.4 Case Study

The City of Hartford, Connecticut, has been incinerating its sludge since 1968. Prior to 1978, the sludge was dewatered using vacuum filters before being fed into the multiple-hearth incinerator. However, this process generated a sludge cake of only 13.8 percent solids, and the plant suffered from frequent breakdowns, high fuel consumption, and the lack of a common operating procedure used by incinerator operators on each shift.

In 1978, Hartford initiated a major effort to reduce operating costs. Between 1978 and 1982, new dewatering equipment and improved operational procedures lowered fuel consumption by 83 percent, which reduced operating costs by $1,300,000 per year.

6.4.1 Belt Filter Press Conversion

Belt filter presses were tested in 1978 and, despite numerous mechanical problems and excessive downtime (25 percent), produced a significantly drier sludge cake than did the vacuum filters. The first press was installed in 1979. It paid for itself in reduced fuel costs in only 6 weeks. By 1982, three additional presses had been installed.

Use of the drier sludge cake reduced fuel consumption by almost 340 l oil/dry mt sludge (82 gal oil/dry ton sludge), increased the incineration rate (dry solids burned per operating hour) by 57 percent, and decreased the average use of incinerators by 23 percent.

6.4.2 New Incinerator Operating Mode

The dramatic success with the belt filter presses encouraged the City of Hartford to pursue other innovative changes to further improve their operations, so the City hired a consultant to develop more fuel-efficient operating procedures. Preliminary analysis of existing incinerator operations found no standard operating procedures. Further, several existing practices were contributing to excessive fuel consumptions, including:

- Combustion in the wrong part of the incinerator.
- High exhaust gas temperatures.
- Use of too much auxiliary air.
- Lack of remote operator controls for airflow dampers and burners.

Based on operational analyses and trial tests, new operating procedures with specific instructions and furnace operating settings were developed. The new procedures were then demonstrated in full plant operation for a 2-week test period. On-the-job operator training was accomplished at the same time. After the demonstration period, the operating procedures were standardized for routine use.

The new operating procedures were characterized by the following general operating guidelines:

- Maximum use of preheated combustion air.
- Lowest possible draft to minimize air leakage.
- Combustion on a low hearth within the incinerator to maximize the drying area.
- Minimization of excess air.

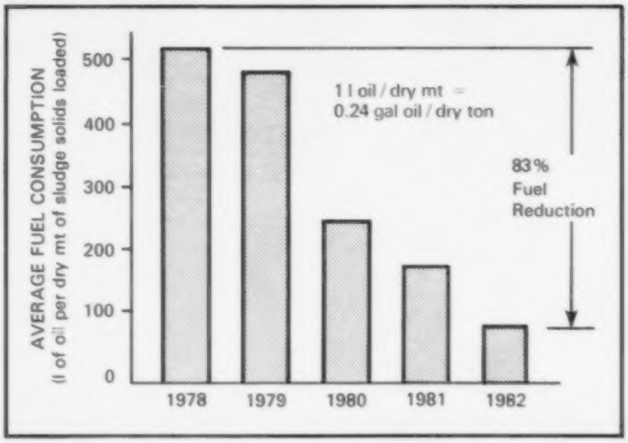


Figure 23. Average Fuel Consumption of Hartford, Connecticut, Incinerators: 1978 to 1982

The specific operating instructions for the new operating procedures were given to the incinerator operators and included procedures for loading sludge into the furnace, incinerator control, controlling combustion zone location, and standby and startup operations.

The average fuel consumption using the new operating procedures was 87.8 l oil/dry mt sludge (21.1 gal oil/dry ton) as compared to 181 l/dry mt (43.5 gal/dry ton) previously—a 51.5 percent reduction. With this improvement, the total fuel reduction achieved by Hartford between 1978 and 1982 amounted to 433 l/dry mt (104 gal/dry ton) or 83 percent which, at the 1982 production level, represented a savings of 4,075 m^3 (1,076,504 gal) of No. 2 fuel oil (see Figure 23).

In addition to reducing direct fuel consumption, the new operating mode provided increased furnace operating flexibility, since the incinerators could now be operated efficiently at loading rates of 50 to 60 percent of capacity. Incinerator operation is also now characterized by cooler maximum operating temperature, more steady state control, fewer particulate emissions, and reduced maintenance on internal incinerator parts.

6.4.3 Cost Savings

The nominal cost savings from fuel reduction were estimated at over $1,076,000 per year assuming a No. 2 fuel oil price of $0.26/l ($1.00/gal). Other energy savings were realized from the belt filter press conversion. An almost 50 percent reduction in air usage reduced the electrical energy requirements of the air compressor by 20 percent, resulting in $200,000 annual savings in electricity costs. Also, the belt presses required less energy than the vacuum filters, resulting in an estimated savings of $25,000 per year. Elimination of the vacuum pumps saved $6,000 per year. The estimated operating cost savings from belt filter press conversion and implementation of the new incinerator operating mode totalled $1,300,000 per year.

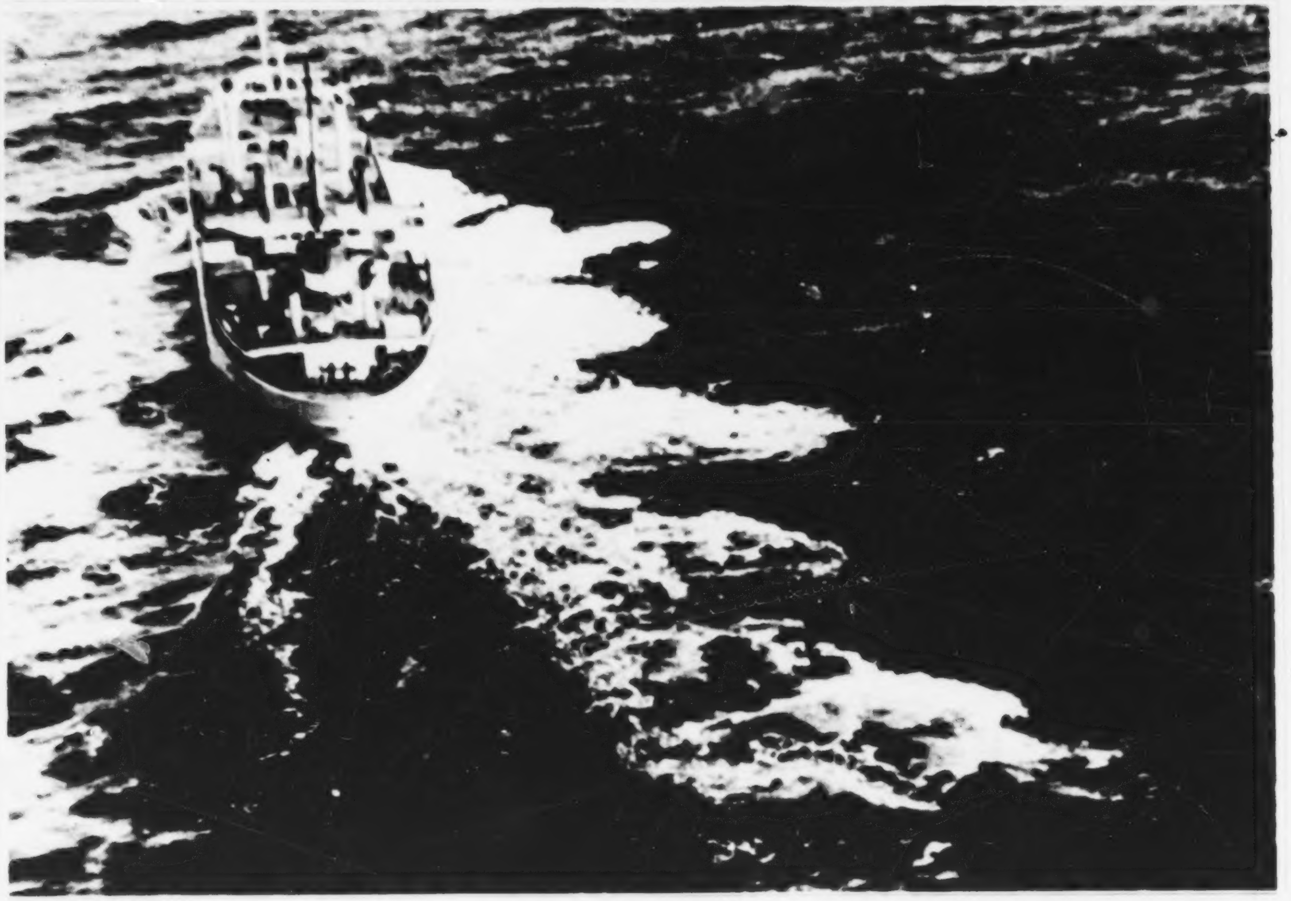
7. Ocean Disposal

7.1 Introduction

In ocean disposal, municipal wastewater sludge is released into a designated area of the ocean, either from vessels at the ocean surface or through outfall pipes. Currently, about 4 percent of the municipal wastewater sludge produced in the United States is ocean disposed. All this volume comes from several large municipalities in the New York City metropolitan area that barge sludge to an offshore disposal site, and from the cities of Los Angeles, California, and Boston, Massachusetts, which discharge wastewater sludge through ocean outfall pipes. However, pipe discharge of sludge is not legal under the Clean Water Act and is being phased out. For this reason, guidance on pipe discharge will not be included in this document.

For communities near the sea, ocean disposal is a relatively inexpensive sludge disposal option. However, it can face the same local public opposition often encountered when siting land-based facilities, and it has generated great concern at state and Federal levels.

When conducted in areas close to shore, ocean disposal can degrade near-shore and shoreline environments; at shallow sites, where there is little dispersion of sludge materials, sludge disposal will degrade the local marine environment. The Marine Protection Research and Sanctuaries Act (MPRSA) which regulates ocean disposal, requires that the EPA select appropriate ocean disposal sites. Attempts to find more suitable areas for sludge disposal have recently led to a deepwater site farther offshore and away from areas of competing ocean uses, which should allow more environmentally acceptable disposal of sludge.



New York City's tanker North River *discharging sewage sludge at the 12-mile sludge dump site in the New York Bight.*

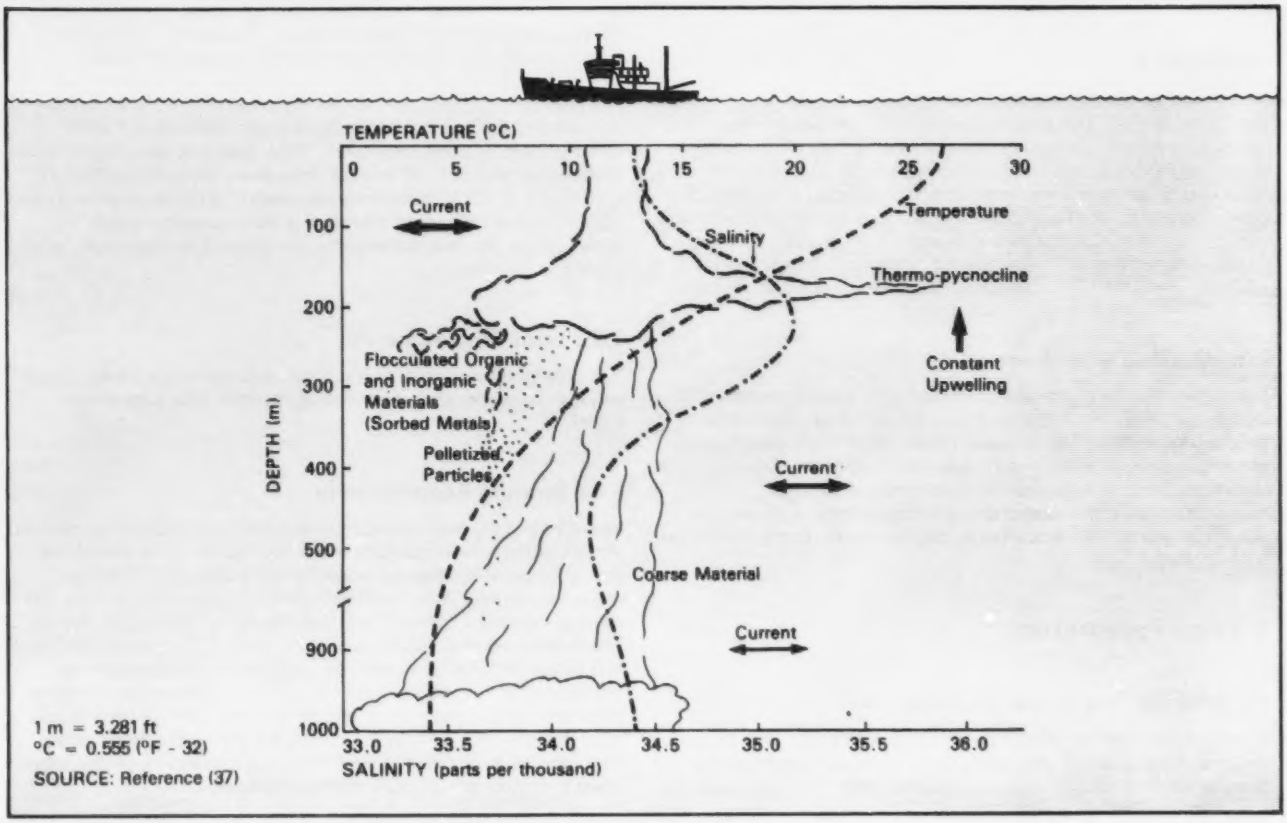
7.2 Process and Performance

The barging of municipal wastewater sludge to an offshore disposal site is currently practiced by several municipal sewerage authorities in the New York City/northern New Jersey area. The process is relatively simple. Self-propelled tankers or towed barges go out to the site where the sludge is released. The sludge immediately begins to disperse, aided by the wake of the vessel. Some sludge constituents, such as volatile hydrocarbons, rapidly evaporate from the water surface and are diluted in the atmosphere. Floatable materials such as grease, oil, and scum tend to remain on the water surface and can be transported long distances from the disposal site by winds and currents.

The rest of the sludge material generally sinks in the ocean as an expanding cloud, which increases in volume as it entrains surrounding water (Figure 24). Heavy particles may sink directly to the ocean floor independently of the cloud. The remaining cloud may proceed directly, although more slowly, to the ocean bottom. The extent to which sinking sludge constituents are dispersed from the disposal area depends on local conditions, such as water depth and currents.

In the ocean, water density often varies from the surface to the seafloor due to changes in temperature and salinity with depth. Even slight density gradients in the water column at a sludge disposal site may cause sludge particles to accumulate at these density fronts. Many contaminants, such as metals and chlorinated hydrocarbons, tend to be associated with fine particles in the sludge, and thus can accumulate at various depths within the water column; the organisms that congregate in these areas have an increased exposure to contaminants.

The fate of particle-associated contaminants that reach the seafloor is difficult to assess. If the area is subject to major storms, currents, or erosional processes, the particles and the associated contaminants may disperse. In less turbulent or shallow areas, particle-associated contaminants could gradually accumulate on the ocean bed.


TEMPERATURE (°C)
0
5
10
15
20
25
30
Current
Temperature
Salinity
Thermo-pycnocline
Constant Upwelling
Flocculated Organic and Inorganic Materials (Sorbed Metals)
Pelletized Particles
Current
Coarse Material
Current
DEPTH (m)
100
200
300
400
500
900
1000
33.0
33.5
34.0
34.5
35.0
35.5
36.0
SALINITY (parts per thousand)

1 m = 3.281 ft
°C = 0.555 (°F - 32)
SOURCE: Reference (37)

Figure 24. Generalized Schematic of the Fate of Sludge Solids Disposed of at Sea

7.2.1 Nutrients

The fate and effect of nutrients contained in sludge depend on local conditions. The nutrients may result in eutrophication if sludge is disposed of near shore or carried near shore by currents. Nutrients may also have a biostimulatory effect in deeper waters. The addition of nitrogen to marine ecosystems may be particularly deleterious. Under normal conditions, nitrogen tends to be the limiting nutrient in biomass production in the water column and in the benthos. Thus, surplus nitrogen could result in the increased production of phytoplankton and other plant life, with concomitant changes in local water quality and species composition.

7.2.2 Pathogens

Pathogens contained in ocean-disposed sludge are a potential human-health risk. Marine organisms, especially filter feeders, can accumulate pathogens. Shellfish are of particular concern because many are sessile organisms that dwell on the ocean floor where the greatest and most persistent accumulation of pathogens, metals, and toxic organic chemicals may occur. In addition, sludge materials discharged near shore may contaminate recreational beaches and pose a public health hazard.

7.2.3 Metals

The effects of the metals contained in sludge on marine ecosystems is not well known. The accumulation of toxic metals into the food chain is a concern because of possible health effects to man from eating contaminated seafood. However, except for methyl mercury, most metals do not appear to biomagnify—that is, to increase in concentration up the food chain. Regulations specifically prohibit the disposal of sludge containing levels of mercury and mercury compounds that would, after initial mixing, raise on-site mercury concentrations by more than 50 percent over background levels.

7.2.4 Organic Chemicals

A number of synthetic organic contaminants sometimes found in sludge are persistent and have the potential for long-term effects in the marine environment. As with metals, food-chain accumulation of toxic organic chemicals is a public health concern. Some organic chemicals, such as halogenated hydrocarbons, tend to bioaccumulate up the food chain, whereas others, such as polycyclic aromatic hydrocarbons, degrade more readily and do not biomagnify.

7.3 Key Parameters

7.3.1 Sludge Treatment Requirements

The *floatable fractions* of sludge should be extracted prior to ocean disposal in compliance with regulations. This is most efficiently done by not including sludges high in floatables (e.g., scum) in the materials destined for ocean disposal.

Thickening and *dewatering* may reduce barging costs. However, the savings in transportation costs must be weighed against the cost of installing and operating the sludge treatment equipment. In general, thickening and dewatering are economical when haul distances are greater than about 160 km (100 mi) round trip. Increasing the solids concentration may change the dispersal patterns of the sludge.

Stabilization is not required prior to ocean disposal. However, it reduces the odor potential of stored sludge, which is particularly important in urban areas. By reducing the number of pathogenic organisms, sludge stabilization also increases the number of use/disposal options available should ocean disposal operations be disrupted. Stabilization through anaerobic digestion also allows methane recovery from the sludge in the digester.

7.3.2 Community Size

Barging is currently practiced only by several large communities in the New York metropolitan area. Many large communities are located on the seacoast and have limited access to land-based alternatives. Their rates of sludge production are high and suited to the capacity of vessels and the associated transportation costs. In addition, large communities can afford the studies needed for permitting and the monitoring programs required for ocean disposal.

Several factors limit the feasibility of ocean disposal for small communities. A small community often does not generate enough wastewater sludge to fill a vessel frequently enough for efficient operations. A small community may also find the costs of program administration difficult to absorb. For these reasons, small communities can only consider ocean disposal in association with other communities.

7.3.3 Land Requirements

The only land requirements for ocean disposal might be for sludge storage, barge docking, and loading facilities (see subsection 7.3.4).

7.3.4 Storage Requirements

Spare barges or, more likely, land and tank capacity are needed for sludge storage during periods when the vessels are in transit and during times when disposal operations are disrupted. Storage requirements vary with the time between sludge hauling trips, the holding capacity of the barges, and the rate of sludge generation. The interval between successive trips is a function of haul distance and vessel availability. In addition, sufficient storage should be available to accommodate several days to several weeks of sludge generation in the event of inclement weather, vehicle breakdown, labor disagreements, or other conditions that could delay barge trips. Sludge thickening, dewatering, and digestion facilities may assist in providing sufficient storage capacity.

7.3.5 Good Practices

The most critical aspect of good practices for ocean disposal is discharging sludge at the correct location. If sludge is discharged elsewhere, the environmental and health effects may be greater and monitoring these effects will be more difficult. Thus, operator responsibility is a significant factor in the successful performance of this disposal alternative.

Another important aspect of good practices is proper program management. In the past, minimal program management has been required for ocean disposal. Management will become more complex as EPA requirements for site monitoring are intensified.

7.3.6 Sludge Quality

EPA regulations (40 CFR 227) only allow ocean disposal of sludges which meet certain standards as demonstrated by several different tests. For example, sludge must be evaluated in tests to demonstrate the absence of undesirable floatable materials and to characterize the waste's physical properties, such as density and solids content. Mercury, cadmium, oil, and grease must be below levels which have undesirable effects on the ecosystem through either toxicity or bioaccumulation. After sludge disposal, synthetic organic chemicals must become diluted to concentrations below marine water quality criteria (where they exist). Organic chemicals that are immiscible or slightly soluble in seawater cannot exceed concentrations above their solubility limits. Regulations require tests to examine the fate of pathogenic organisms in sludge, and to assess the toxicity of the waste and the bioaccumulation of certain sludge contaminants up the marine food chain.

Failure of a sludge to pass these environmental tests does not automatically preclude ocean disposal. If a municipality can demonstrate that ocean disposal poses the least amount of environmental degradation of all the available sludge use/disposal options, an ocean disposal permit may be granted (see subsection 7.3.10).

7.3.7 Public Acceptance

Ocean disposal generally has more favorable public acceptance than land-based sludge use/disposal alternatives. Any opposition to disposal at a specific site is usually encountered during site designation (see subsection 7.3.10) when conflicting site uses, such as fisheries or recreation, must be resolved.

7.3.8 Transportation Requirements

Sludge must first be transported from the treatment plant to the vessel loading facility. In a coastal community, these may be very close or at the same location. However, for an inland town, overland sludge transport would be an important consideration.

Sludge is hauled to the disposal site either by self-propelled tankers or in standard bulk container barges that are hauled by tugboats.

7.3.9 Energy Usage

The primary energy requirement of ocean disposal is fuel consumption by the tugboats or self-propelled vessels.

7.3.10 Regulatory Approval

Federal controls on ocean disposal were instituted in the early 1970s under the Clean Water Act and the Marine Protection Research and Sanctuaries Act (MPRSA). Regulations promulgated under MPRSA define the circumstances under which the EPA will grant a permit for ocean disposal of sludge. This is the only instance in which the EPA becomes directly involved in sludge management planning.

The regulatory structure of the MPRSA consists of two phases: (1) EPA designates sites for disposal of specific materials, and (2) EPA issues permits to dispose of materials at these sites. These regulations are currently being refined.

Site designation is based on such factors as proximity to beaches and the effect of disposal on the marine environment. Permitting decisions for sludge disposal are based on such factors as the volume and characteristics of the sludge and the availability and effect of alternative disposal methods. A permit to ocean dispose sludge at a site is granted only if the applicant can clearly demonstrate that no practicable alternative is available that has less impact on the total environment. Because the long-term costs of a degraded marine environment may be greater than the short-term savings to municipalities, EPA does not sanction a choice of ocean disposal based solely on economic considerations.

Shortly after the passage of MPRSA in 1972, EPA designated the "12-Mile" Site off the New York/New Jersey metropolitan area for use on an interim basis, but that designation expired at the end of 1981. Sludge disposal has continued at that site under court orders. EPA has designated a replacement site. Known as the "106-Mile" Site, it is located off the Outer Continental Shelf 217 km (135 mi) southeast of the entrance to New York Harbor and 212 km (132 mi) from Atlantic City, New Jersey.

EPA selected the "106-Mile" Site over the closer "12-Mile" Site for several reasons. The primary concern was the degradation of the quality of the New York Bight, which is the section of the Atlantic Ocean within the bend of the coastline between Long Island and New Jersey. Although sludge disposal is not the only cause of the degraded condition of this area, it is a contributor to the problem, and one that can be removed by moving the disposal site.

There is greater potential for dispersion at the "106-Mile" Site than there is at the "12-Mile" Site. Although the "106-Mile" Site has a permanent density stratification at about 200 m (650 ft), other hydrographic features increase dispersion and the transport of materials out of the disposal area. These features include prevailing currents, and large eddies that break off from the Gulf Stream and traverse the site about 70 days per year. The "106-Mile" Site has been used for the disposal of various materials since 1961, and no long-term adverse ecological effects from these activities have been detected.

Ocean disposal is the sludge use/disposal option least favored by EPA. The administrative and technical aspects of the permitting process are usually difficult and costly to a municipality, although they are still possible when ocean disposal is the preferred alternative. The emerging Federal policy to promote the productive use of sludge and to encourage states to assist local communities in finding adequate land-based sludge disposal capacity will provide capacity lost by EPA restrictions on ocean disposal.

7.3.11 Cost Factors

Ocean disposal has been a relatively low-cost sludge disposal option. However, current and projected requirements related to hauling sludge to deepwater sites, permitting, and site monitoring increase the cost of ocean disposal programs. These costs tend to make ocean disposal most feasible for large municipalities.

Other capital and operating costs associated with ocean disposal are still relatively low, because fuel consumption during vessel transport is low, and tugboats that may be used in ocean disposal operations are generally rented.

8. Evaluating Alternatives

8.1 Introduction

Five methods are widely employed to use or dispose of wastewater sludge: land application, distribution and marketing, landfilling, incineration, and ocean disposal. Their applicability to a particular municipality depends on many factors, including the source and quantity of wastewater sludge, geographic location of the community, hydrogeology of the region, land use, economics, public acceptance, and regulatory framework. Often, a community must select and implement more than one sludge use/disposal option, and must develop contingency and mitigation plans to ensure reliable capacity and operational flexibility.

Determining which of the various use/disposal options is most suitable for a particular community is a multistage process. The first step is to define the needs—that is, to determine the quantity and quality of sludge that must be handled and estimate future sludge loads based on growth projections. Then alternative sludge use/disposal options, that meet these needs and that comply with applicable environmental regulations, must be broadly defined. Unsuitable or noncompetitive alternatives must be weeded out in a preliminary evaluation based on readily available information. For example, seldom would a rural midwestern agricultural community elect to ocean dispose or incinerate its wastewater sludge. Resources are then focused on a more detailed definition of the remaining alternatives and on their evaluation. Final selection of an option may require a detailed feasibility study.

Several systems are available for evaluating alternatives. For example, "Cost-Effectiveness Analysis" is used to compare alternatives on the basis of their cost. Cost-effectiveness analysis is essential for sludge management projects that are to be supported with the aid of EPA's Construction Grant funding. Details of its requirements can be found in reference (38).

One planning approach for tallying the nonmonetary and often subjective factors is a "System of Accounts," which allows the proposed alternatives to be evaluated from different "accounts" (39), including:

- Compatibility with land uses in close proximity to the proposed site.
- Energy usage.
- Recovery of resources.
- Reliability.
- Demonstrated ability to operate.
- Operating life of the facility.

In this approach, the different accounts selected for evaluation are scored numerically to tally the comparative strengths and weaknesses of the various alternatives. The "System of Accounts" is a valuable tool for demonstrating the objectivity of the planning to groups that may oppose project alternatives.

In the recent past, sludge management has had to deal specifically with the issue of risk, and a "Risk Assessment" has been advanced as a tool to aid local decision-making (40,41). Because of the

	LAND APPLICATION	DISTRIBUTION AND MARKETING	LANDFILLING	INCINERATION	OCEAN DISPOSAL
Sludge Treatment Requirements					
Dewatering	◒	●	●	●	○
Stabilization	●	●	◒	○	○
Community Size	○	◒	○	●	●
Land Requirements					
Land Availability	●	○	●	○	○
Hydrogeology	●	○	●	○	○
Storage	●	●	◒	◒	●
Good Practices	●	●	●	●	●
Sludge Quality					
Pathogens	●	●	○	○	○
Toxic Organic Chemicals[a]	◒	◒	◒	◒	◒
Metals	●	●	◒	◒	◒
Nutrients	●	◒	○	○	○
Public Acceptance					
Odors, Aesthetics	●	●	●	●	◒
Traffic	●	◒	●	◒	○
Transportation Requirements	●	●	●	○	◒
Energy Usage	○	◒	○	●	○
State and Federal Regulatory Approval	Site-Specific	Little Coverage	Site-Specific	State and Federal	Federal
Cost Factors	Variable[b]	Variable[b]	Low[b]	High	Low[b]

[a] Based on the most current EPA information; however, assessments of impact continue.

[b] Heavily influenced by transportation costs.

● Very Important
◒ Moderately Important
○ Not Important

Figure 25. Comparison of Key Parameters that Influence the Selection of Sludge Use/Disposal Options

difficulty in collecting the data needed for such an assessment, and the difficulty in making needed assumptions and interpreting the results of the analyses, risk assessment is only recommended for large-scale planning processes.

Preparing for implementation involves securing permits; financing; contracting; demonstrating to regulatory agencies compliance with environmental standards; and verifying that the project meets program design expectations.

Chapters 3 through 7 of this guidance document describe the five major sludge use/disposal options individually and discuss the key parameters that affect their implementation. These parameters are summarized for comparison in Figure 25. This chapter provides a basis for a preliminary comparison of the options through a broad overview of the key parameters. However, each community must ultimately tailor its evaluation strategy to meet its local needs and conditions. Reference (42) provides additional guidance.

Although the emphasis of this guidance document is sludge use/disposal, sludge management actually encompasses a series of activities, starting with the production of sludge in wastewater treatment, continuing through sludge treatment and transportation, and ending with sludge use/disposal. The treatment process and transportation options and requirements for the five use/disposal options are shown in Figure 26. Ideally, these processes should be selected and designed as a unit to optimize efficiency and cost effectiveness. However, this can only be done under ideal situations. Municipalities usually have parts of a sludge management system already in place, and this will influence their selection of new or additional processes. Clearly, the possibility of replacing or modifying existing wastewater and sludge treatment facilities should not be overlooked, since it may result in long-term cost savings and more acceptable sludge management.

8.2 Key Parameters

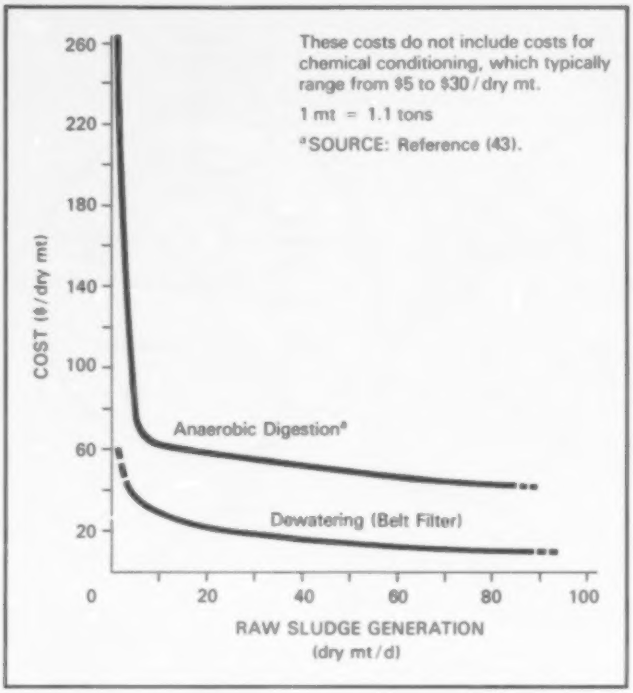
8.2.1 Sludge Treatment Requirements

Sludge use/disposal options require some form of prior sludge treatment: thickening, stabilization, conditioning, and dewatering. The costs of treatment can be significant. To illustrate this, typical costs for anaerobic digestion and dewatering processes are provided in Figure 27. These costs assume no prior processing of the sludge before it enters the stated treatment process.

Sludge Type	Sludge Treatment			Transportation
	Thickening	Stabilization	Dewatering / Drying	
Primary ▲●◆■★	Gravity ▲●◆■★	Anaerobic Digestion ●■	Filter Press ▲◆■	Rail ◆
Secondary ▲●◆■★	Flotation ▲●◆■★	Aerobic Digestion ●◆■	Belt Press ▲●◆■★	Truck ●◆■
Tertiary ▲●◆■★		Lime Treatment ●■	Drying Beds ●■	Pipeline ▲●
		Composting ◆	Centrifuge ▲●◆■★	Barge ★
			Vacuum Filter ▲●◆■★	
			Heat Drying ◆	

Key	
●	Land Application
◆	Distribution and Marketing
■	Landfilling
▲	Incineration
★	Ocean Disposal

Figure 26. Typical Sludge Treatment and Transportation Processes Used Prior to Sludge Use/Disposal Options



These costs do not include costs for chemical conditioning, which typically range from $5 to $30/dry mt.

1 mt = 1.1 tons

[a] SOURCE: Reference (43).

Figure 27. Typical Costs for Anaerobic Digestion and Dewatering as a Function of Sludge Generation

Sludge treatment processes, however, produce sidestreams which must be treated to remove contaminants prior to discharge. Sidestreams are generally reintroduced to the wastewater stream entering a treatment plant. Treatment of solids in the sidestreams may represent a large additional load and a considerable expense to the wastewater treatment system. Thus, the impacts of any new sidestream on wastewater treatment facilities must be considered when evaluating the merits of a new or additional sludge treatment process.

8.2.2 Community Size

The economics of sludge management are highly influenced by the size of the municipality. Wastewater treatment plants and the communities they serve can be divided into three categories based on the volume of wastewater inflow: small plants that process less than 1 million gallons of wastewater per day (1 mgd)[a], medium plants that process between 1 and 10 mgd, and large plants that handle more than 10 mgd. The vast majority (12,000) of wastewater treatment plants are small, with 2,700 medium-sized and only 500 large. The volume of sludge a community produces is related to the volume of wastewater and types of treatment processes. As a rule of thumb, wastewater treatment plants generate approximately 240 grams of sludge solids for every cubic meter (m^3) of wastewater processed to secondary levels (11).

Based on current practice (44), small and medium-sized wastewater treatment plants tend to *land apply* or *landfill* sludge, whereas larger plants choose from among all five options. Almost all *ocean disposal* and most *incineration* systems currently operating are used by large plants (Figure 28). Incineration has been the method of choice for many large communities because they generate a large volume of sludge and have limited land available for land application or landfilling. In addition, the initial capital costs of an incinerator, the need for highly trained operators, and continuing high costs for equipment and maintenance are more easily absorbed by large communities.

8.2.3 Land Requirements

The proximity of disposal or use sites is a major factor in evaluating alternatives. For *land application* and *landfilling*, an adequate amount of suitable land must be available within an affordable transportation distance (see subsection 8.2.8).

The *amount* of land needed is a direct function of sludge quantity, its characteristics, how it has been treated, and the use/disposal option chosen. Figure 29 compares the total leased or purchased land that is needed to accommodate all the sludge production from treatment plants of various sizes for a period of 10 years at typical sludge loading rates. Table 14 gives the information used in preparing Figures 29 and 30. In every situation portrayed, the raw sludge is anaerobically digested, which reduces by 50 percent the mass of sludge solids to be further processed. Note that wide trench landfills, codisposal landfills, dedicated land disposal, and composting typically require the least amount of land; narrow trench landfills require slightly more land; and agricultural application, land reclamation, and forest application require the most land.

The range of land requirements for land application and landfilling based on extreme sludge loading rates are shown in Figure 30. Situation-specific factors, such as sludge nitrogen, sludge metal concentrations, and climatic limitations on sludge application, will determine where in this range a particular system would fall. The land requirements are for sites that are *suitable* for land application or landfilling—that is, that have appropriate hydrogeology, zoning and adjacent land use, and proposed future use.

Since composted sludge is frequently applied in suburban or nonagricultural commercial operations, it may be a feasible alternative where adequate land is not available for other sludge disposal options. Also, because composted sludge may have a higher value to users than other forms of sludge, the municipality may be able to charge a fee for the compost, and users may have incentive to transport the sludge themselves, allowing more distant sites to be considered.

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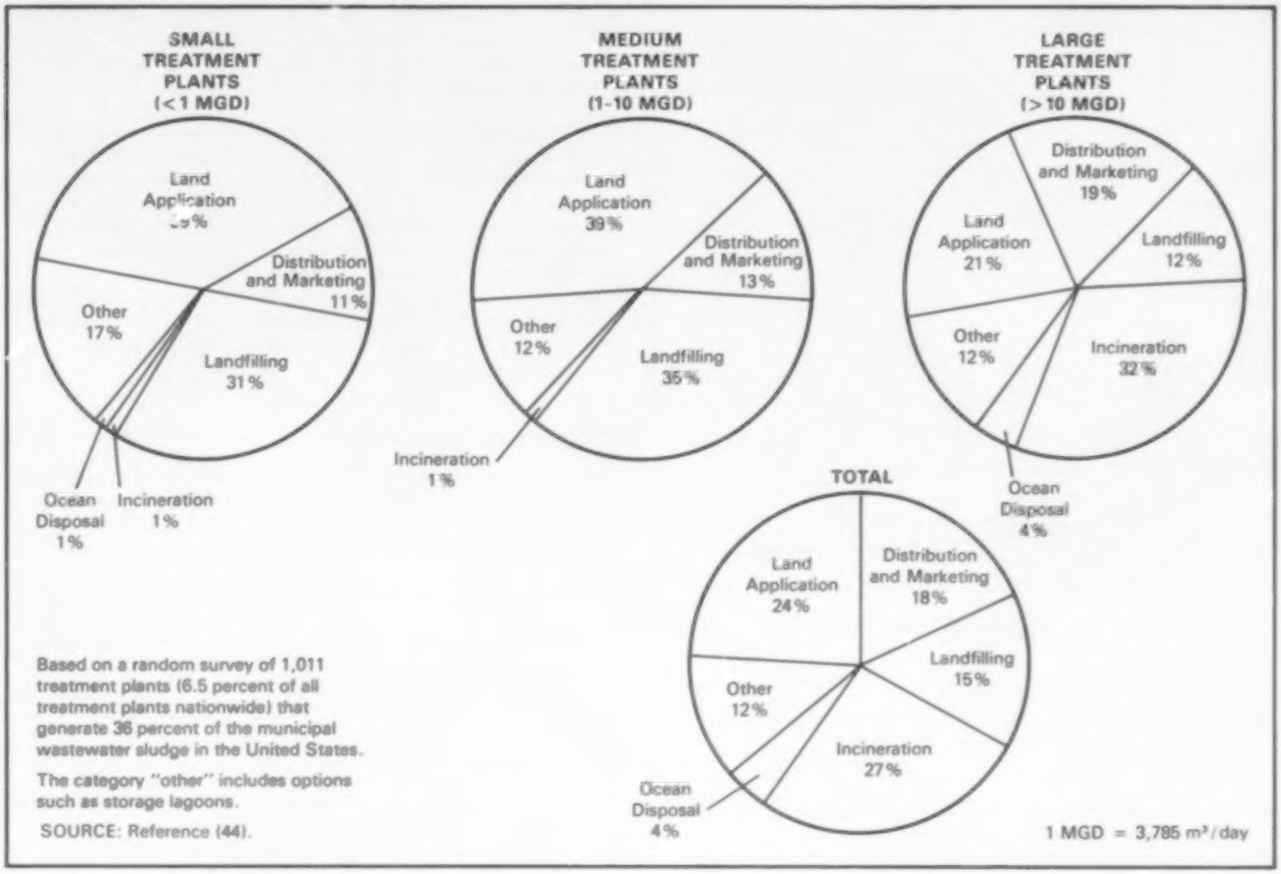
[a] 1 mgd = 3,785 m^3/d.



Based on a random survey of 1,011 treatment plants (6.5 percent of all treatment plants nationwide) that generate 36 percent of the municipal wastewater sludge in the United States.

The category "other" includes options such as storage lagoons.

SOURCE: Reference (44).

1 MGD = 3,785 m³/day

Figure 28. The Relative Distribution of Sludge (Dry Weight) to the Five Use/Disposal Options Among Small, Medium, and Large Treatment Plants

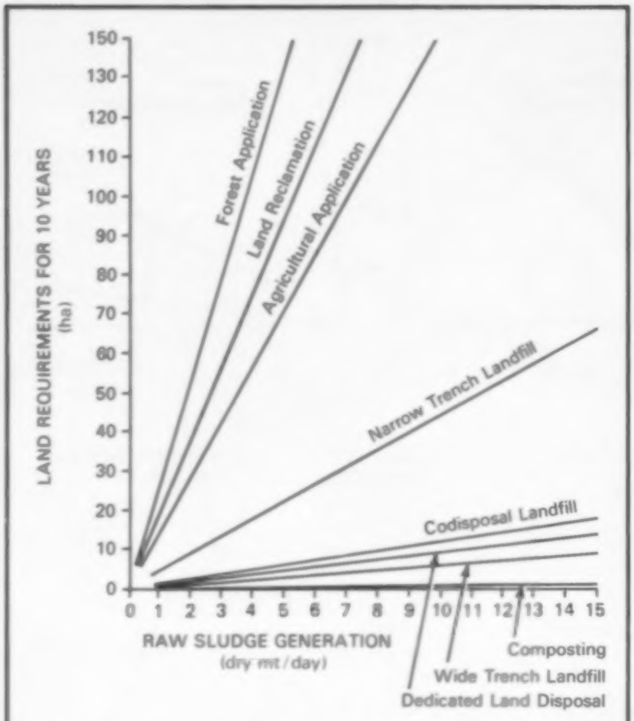
Ocean disposal is probably viable only if the community is located within about 40 km (25 mi) of a suitable dock site that can offer barge transport of sludge, and if there is an approved offshore dumpsite within economical transport range.

Land availability is occasionally a limiting factor in *incineration* if a suitable site for ash disposal does not exist within a reasonable distance of the treatment plant.

8.2.4 Storage

Sludge storage is usually a component of all sludge management systems. For land application, storage is necessary because climatic conditions and variations in agricultural activity prevent year-round application. For incineration and landfilling, climatic constraints are less important, but storage is still necessary to accommodate fluctuations in sludge volume, operational difficulties, and

Drying beds—a method of sludge dewatering—can be used to store sludge. The bed on the left contains dried sludge. The bed on the right contains partially dried sludge.



In every case illustrated, the sludge generated during wastewater treatment is anaerobically digested prior to land application or landfilling (see Table 14).
Incineration and ocean disposal, not shown here, have insignificant, but finite, land requirements.

DLD = dedicated land disposal 1 mt = 1.1 tons 1 ha = 2.471 ac

Figure 29. Typical 10-Year Land Requirements for Land Application, Landfilling, and Composting of Municipal Wastewater Sludge as a Function of Sludge Generation

equipment failures. Sludge storage may also be necessary because wastewater treatment, sludge treatment, and sludge use/disposal sometimes operate on different schedules.

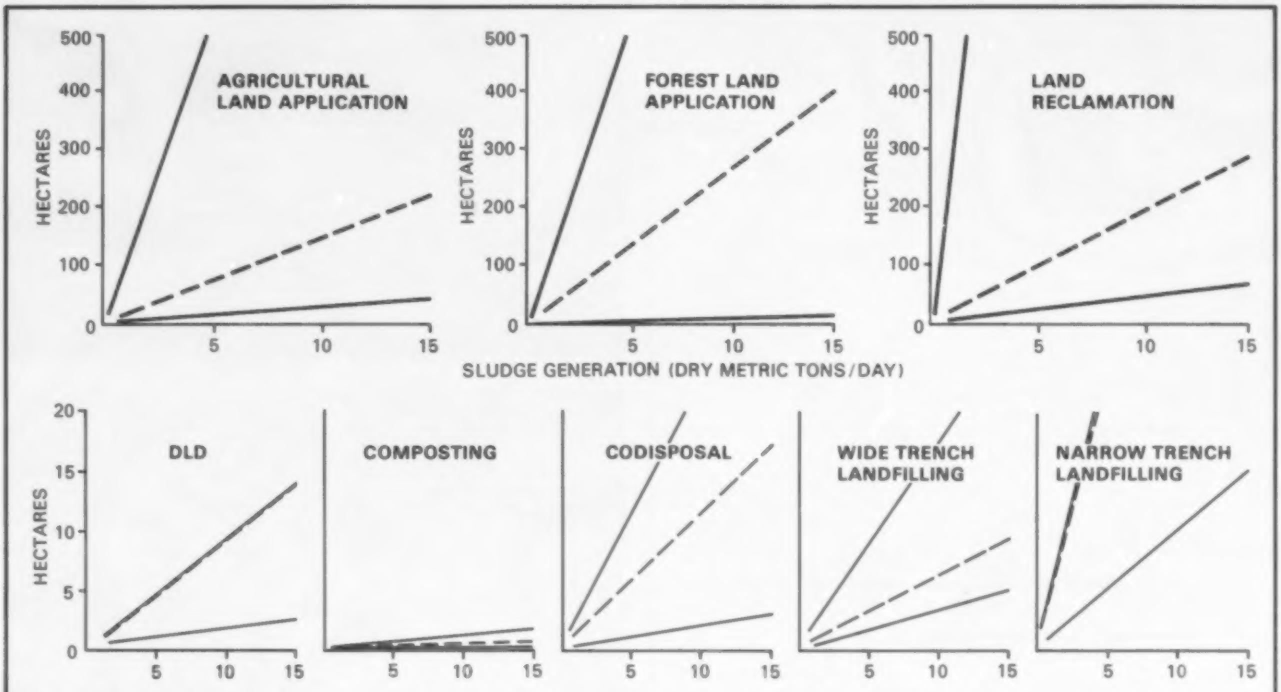
Some storage is provided by thickening, stabilization, and dewatering systems—particularly drying beds, drying lagoons and digestion facilities. Specialized storage facilities may also be needed.

8.2.5 Good Practices

Site management encompasses all the operations of a sludge management program. Depending on the use/disposal option, site management may include preparing the site; training operators;

Monitoring is a key element of good sludge use/disposal operations. Shown here are several types of monitoring.

- a. *Collection of leaf samples from soybeans fertilized with composted sludge. These samples will be analyzed for water, nitrogen, and heavy metals to help determine the fertilizer value of the sludge compost.*
- b. *Collection of forage samples from strip-mined land that has been reclaimed with sludge compost. The samples will be analyzed for heavy metals.*
- c. *Extraction of a groundwater sample from a land application site.*



Typical land requirements for each use/disposal option, which are compared in Figure 29, are indicated by a dashed line.
In every case illustrated, the sludge generated during wastewater treatment is anaerobically digested prior to land application or landfilling (see Table 14).
Incineration and ocean disposal, not shown here, have insignificant, but finite, land requirements.
DLD = dedicated land disposal 1 mt = 1.1 tons 1 ha = 2.471 ac

Figure 30. The Range of 10-Year Land Requirements for Land Application and Landfilling of Municipal Wastewater Sludge as a Function of Sludge Generation

ensuring the availability of utilities and needed materials (i.e., soil, water, fuel, electricity); selecting the sludge application method and crops to be grown; and determining the extent of the environmental monitoring and controls required.

Once a use/disposal system is in operation, its effectiveness depends to a large extent on the skill and commitment of the individuals involved in the operations, including equipment operators and monitoring staff. Selecting a sludge management alternative is therefore a commitment to hire, train, and retain qualified personnel needed to keep the system functioning optimally. Without appropriate site management, even the best designed sludge management system will create unacceptable environmental effects and community hostility.

Each community generating sludge is responsible for providing sustained sludge disposal and use capacity. While contractor services help provide this capacity, the community should carefully monitor operations to ensure the continued use of good practices.

8.2.6 Sludge Quality

The types and concentrations of pathogens, persistent organic chemicals, metals, and nutrients in sludge may pose health and environmental concerns. If sludge quality appears to be a limiting factor for an otherwise desirable use/disposal option, a municipality may want to consider controlling sludge quality at the source by requiring industrial wastewater pretreatment or a modification of the industrial processes that produce the wastewater. This approach has been successful in many municipalities and is being increasingly recognized as an important tool in sludge management (see Table 15 for examples).

Table 16 lists the estimated contribution of 13 major industries to the levels of six metals of concern in U.S. wastewater collection systems. A municipality with a high concentration of one of those metals in its sludge can use this table to gain a preliminary idea of which industry may be a likely candidate for further pretreatment requirements.

Table 14. Assumptions for Figures 29 and 30.

For every m^3 of wastewater treated with primary and activated sludge processes, 230 g of raw sludge solids are produced (1,900 lb / mil gal). The raw sludge is then anaerobically digested.

Of the initial raw solids content, 75 percent is volatile. Fifty percent of the volatile solids are removed during anaerobic digestion, and 75 percent of the remaining solids are captured from the effluent stream.

After digestion, 108 g of sludge solids remain to be treated and disposed for every m^3 of wastewater treated.

	Application frequency	Low loading	Typical loading	High loading
Agricultural application	Apply repeatedly to the same sites ever year	2 dry mt / ha / yr	15 dry mt / ha / yr	70 dry mt / ha / yr
Forest application	Apply to each site one time every 5 years	10 dry mt / ha / 5 yr	40 dry mt / ha / 5 yr	220 dry mt / ha / 5 yr
Land reclamation	Apply to a site one time only	7 dry mt / ha	112 dry mt / ha	450 dry mt / ha
Dedicated land disposal	Apply repeatedly to the same site	220 dry mt / ha / yr	227 dry mt / ha / yr	900 dry mt / ha / yr
Composting[a]	Apply to static piles with a 28-day extended detention	4.2 dry mt / ha	6.7 dry mt / 0.07 ha / day	11.2 dry mt / ha
Wide trench landfill	Apply 20% solids content sludge to a site one time only	1,200 dry mt / ha	3,439 dry mt / ha	5,480 dry mt / ha
Narrow trench landfill	Apply 20% solids content sludge to a site one time only	460 dry mt / ha	482 dry mt / ha	2,120 dry mt / ha
Codisposal	Apply 20% solids content sludge to a site one time only	900 dry mt / ha	1,800 dry mt / ha	7,900 dry mt / ha

[a] Only composting and storage facility land is required.

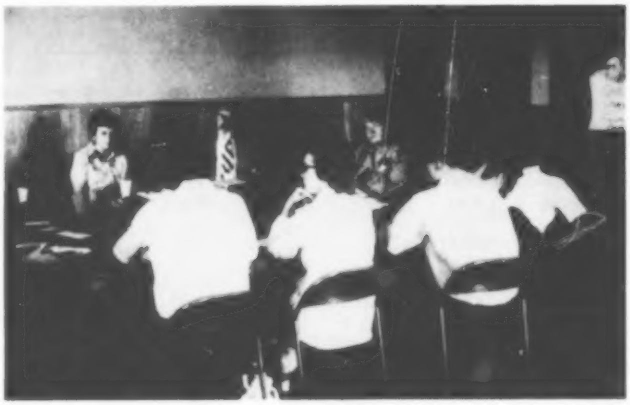
SOURCE: References (4,9,11,16,43).

8.2.7 Public Acceptance

Public acceptance is crucial to the success of any sludge use/disposal option. All five options may encounter public resistance. This resistance is often rooted in a lack of understanding of the problems, and in a feeling by the community that they have been excluded from the decision-making process. However, it may also stem from justified concerns about effects. Frequently raised concerns include odors, poor aesthetics, noise and traffic congestion in residential areas, and health or environmental risks.

To minimize public opposition, the evaluation process should include some form of public involvement. This program should be tailored to the scope of the project and the potential for public concern. Goals of such a program may include:

- Informing the public about the evaluation process and any decisions that are made.



Involving the public in the decision-making process helps pave the way for a successful sludge use / disposal program.

- Educating the public about the problems and solutions of sludge management.
- Involving the public in the decision-making process.

Whatever its scope, a public participation program should be implemented early in the evaluation process. This allows time for compromise, accommodation, and changes to the plan in case of any serious public opposition. Further information on such programs can be found in references (26) and (42). Once a sludge management system is in place, proper operation and management are essential to maintain public support for the program. In some cases, public dissatisfaction has closed down operations and required the selection and construction of a replacement system. Any concessions made to the public during the selection process must be honored. For example, in Dickerson, Maryland, sludge haulers were ticketed and fined if they violated any of the rules for transportation of sludge agreed upon with the community.

Table 15. Metal Reduction in Sludge by Industrial Pretreatment

	Chicago			Buffalo		
	Level (mg/kg)			Level (mg/kg)		
Metal	Before	After	Removal (%)	Before	After	Removal (%)
Cadmium	190	54	71.6	100	50	50.0
Chromium	2,100	790	62.4	2,540	1,040	59.1
Copper	1,500	282	81.2	1,570	330	79.0
Lead	1,800	486	73.0	1,800	605	66.4
Nickel	1,000	77	92.3	315	115	63.5
Zinc	5,500	2,800	49.1	2,275	364	84.0

SOURCE: Reference (45).

8.2.8 Transportation Requirements

Sludge can be transported by truck, pipeline, rail, or barge. The choice of transportation method depends on the use/disposal method chosen, the volume and solids content of the sludge, and the distance to and number of destination points. Trucks and pipelines are the most common form of transport. Barge transport is used almost exclusively for ocean disposal. Rail transport, although potentially useful, is rarely used in the United States, due to the difficulty in unloading rail cars and the system's fixed location. Pipelines can be used cost effectively for long-distance pumping of liquid sludge (usually less than 8 percent solids) but have been used for sludges of up to 20 percent solids over short distances.

Truck transport allows greater flexibility than any other transport method. Destinations can be changed with little advance notice, and the sludge can be distributed to many different destinations. If trucks must be routed along residential or secondary streets, then public concern about congestion and the risk of sludge spills must be considered. Most land application programs use truck transport, either alone or after sludge transport by pipeline or rail to an intermediate storage facility. Liquid sludge of up to a 10 percent solids concentration (depending on its viscosity) can be transported in tank trucks. Dewatered sludge with a greater than 10 percent solids concentration can usually be transported in open trucks with watertight seals if precautions are taken to prevent spillage. Dried and composted sludges of an approximately 50 percent or greater solids concentration can be transported without watertight seals or splash guards.

The practical limit for a truck haul distance is about 16 to 32 km (10 to 20 mi) one way (42). For land application of liquid sludge, the land must generally be within about a 16-km (10-mi) radius of the treatment plant for transportion to be economical. Mechanically

Table 16. Estimated Metal Loadings from Indirect Industrial Dischargers Into U.S. Municipal Sewer Systems [1,000s of kg (lb)/yr]

Metal	Inorganic chemicals	Metal finishing	Steel	Ore mining	Coil coating	Porcelain enameling	Foundries	Pesticides	Petroleum refining	Ink	Paint	Pulp & paper	Leather tanning
Cadmium	5 (11)	42 (92)	0.9 (2)	2.7 (6)	0.05 (0.1)	3.2 (7)	–	–	0.003 (0.006)	–	–	–	–
Chromium (trivalent)	684 (1,504)	2,871 (6,316)	191 (421)	15 (33)	–	–	–	–	62 (137)	–	–	–	2,055 (4,522)
Chromium (hexavalent)	–	1,052 (2,315)	16 (36)	–	160 (352)	1.4 (3)	–	–	1.4 (3)	0.5 (1)	–	–	–
Copper	32 (70)	2,037 (4,482)	55 (121)	248 (545)	0.14 (0.3)	2.7 (6)	0.5 (1)	–	7 (15)	0.14 (0.3)	0.09 (2)	–	–
Lead	176 (388)	67 (147)	48 (106)	23 (51)	0.9 (2)	25 (54)	3.6 (8)	–	2.2 (5)	1.4 (3)	–	–	–
Nickel	2.3 (5)	2,472 (5,439)	170 (374)	58 (128)	0.9 (2)	47 (103)	0.04 (0.08)	–	1.4 (3)	–	–	–	–
Zinc	201 (443)	1,860 (4,092)	355 (782)	636 (1,400)	45 (98)	54 (118)	11 (24)	1.4 (3)	36 (80)	–	25 (56)	20 (44)	–

SOURCE: Adapted from Temple, Barker and Sloan summary of EPA data, January 31, 1983.

Sludge transportation requirements are a key consideration when evaluating sludge treatment, use, and disposal alternatives. Trucks are the most common method of sludge transportation. Shown here is a 24,600-l (6,500-gal) liquid sludge tank truck.

dewatered sludge can generally be economically transported to a land application or landfill site up to about 22 km (20 mi). Air-dried sludges, which can have solids concentrations in excess of 55 to 60 percent, can be economically transported a greater distance. In evaluating transportation costs, the cost of dewatering must be weighed against the cost savings that can result from transporting a drier sludge.

8.2.9 Energy Usage

Energy usage is a concern because of the unpredictable nature of fuel costs. The most significant energy uses in sludge management are:

- Auxiliary fuel in incineration.
- Transportation costs in land application, landfilling, ocean disposal.
- Sludge treatment—particularly dewatering.
- Heating and mixing sludge in anaerobic digesters.
- Aerating sludge during aerobic digestion.
- Moving, aerating, and turning sludge during composting.

8.2.10 State and Federal Regulatory Approval

Most sludge management options are subject to minimum Federal regulations, and usually to state regulations and local permit requirements. The regulatory climate at each level can significantly influence the cost and feasibility of a sludge management option.

Several different state and local agencies may have jurisdiction over sludge management. The types of regulations and the feasibility of obtaining the requisite permits vary dramatically from jurisdiction to jurisdiction. The review period for any permit application will vary depending on the regulatory agency, its procedures, the backlog of applications preceding it, and other factors. This process takes at least 1 month and often longer. A long regulatory review may delay investment and thus increase the capital costs of a use/disposal option. The management effort needed to gain approvals may render the option less attractive than it originally seemed. In addition, state and local regulations may directly limit the feasibility of an option. For example, Massachusetts regulations as of 1984 require that specific site approval be obtained prior to land application of any sludge or sludge product that contains more than 2 milligrams per kilogram (mg/kg) of cadmium. This requirement—far more stringent than Federal regulations—essentially eliminates distribution and marketing as a sludge use/disposal option for sludge products of greater than 2 mg/kg cadmium because the destination of the sludge product is generally not known.

8.2.11 Cost Factors

The major cost elements for each option are shown in Figure 31. For ease of comparison, these costs have been broken down into

	LAND APPLICATION	DISTRIBUTION AND MARKETING	LANDFILLING	INCINERATION	OCEAN DISPOSAL
Sludge Treatment	○	●	○	○	○
Transportation	●	○	●	○	●
Capital	○	●	●	●	○
Operation and Maintenance	○	●	○	●	○
Administration	○	○	○	○	○

● Very Important
○ Usually Less Important

Figure 31. Major Cost Factors for the Five Sludge Use/Disposal Options

five categories: sludge treatment costs, sludge transportation costs, capital costs, operating costs, and administration. Sludge treatment and transportation costs are featured separately because they vary considerably from one municipality to another. In the case of land application, cost evaluation should also consider any income from the sale of sludge, sludge products, or energy.

Economic comparison of use/disposal alternatives is a relatively specialized task, generally performed by an engineering consulting firm. However, Figure 32 provides a rough idea of comparative economics of the different use/disposal alternatives. Actual costs may vary considerably depending on the local situation. References (38,43) and engineering economics texts provide more detailed information on comparative economic evaluations.

One factor to consider in evaluating costs is system reliability. Unplanned service disruptions and the management time necessary to resolve them can result in unexpected cost increases. Price changes will also impact the operating costs of any long-term project, and the sensitivity of operating costs to price changes must be carefully assessed. In particular, energy costs and contractor escalator clauses should be carefully considered.

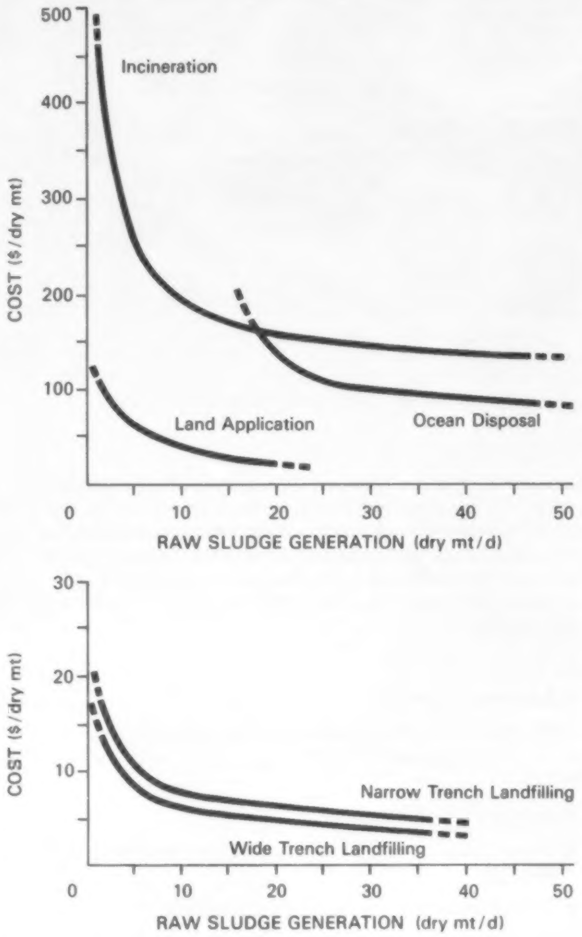
In some cases, part of the costs of feasibility studies and construction are eligible for funding under the EPA Construction Grants program and under individual state programs. For more information about funding, consult reference (38) and state water pollution control programs.

8.3 Sample Evaluation

The following hypothetical example is intended to illustrate the types of issues and considerations that must be addressed when evaluating sludge use/disposal alternatives. The example is a hypothetical situation; however, it does demonstrate the complexity of the decision-making process. Although several key factors enable the field of potential alternatives to be narrowed down early in the decision-making process, there is rarely one clearly preferable alternative. Final selection may take months and often years of study and negotiation among municipal officials, concerned citizens, and regulators to arrive at an acceptable compromise.

Green Valley, USA

Green Valley, a community with a population of about 2,500, is located in a rural agricultural area of the midwest. The town's primary and secondary treatment plant is located on the outskirts of town. Handling 1,900 m³ (0.5 mil gal) of wastewater per day, the plant produces 12.5 wet mt (13.7 wet tons) of liquid sludge (2 percent solids) each day, or about 90 dry mt (110 dry tons) of sludge solids each year. The town was meeting its sludge management needs by anaerobically digesting the liquid sludge, thickening it to a solids content of 5 percent, and storing it in lagoons with occasional removal to a landfill or sporadic land application to either municipal or agricultural land. However, with community growth, and more stringent state and Federal treatment requirements that increased sludge generation, residents and their elected officials needed to choose a more environmentally sound



Prior to land application of the liquid sludge, the raw sludge was anaerobically digested.
Prior to landfilling, the raw sludge was anaerobically digested and dewatered on a belt filter press to a 20 percent solids concentration.
Prior to incineration, the raw sludge was conditioned with an organic polymer and dewatered on a belt filter press to a 20 percent solids concentration.
Costs do not include the costs of sludge treatment prior to final use or disposal.

1 mt = 1.1 tons

Figure 32. Typical Costs for Land Application, Landfilling, Incineration, and Ocean Disposal of Municipal Wastewater Sludge as a Function of Sludge Generation

use/disposal option. Because of a local industry—the predominant livelihood of the town—the digested sludge contains approximately 25 mg/kg of cadmium, which exceeds the state's regulatory limit of 20 mg/kg for land application to private farmland. No other chemicals or metals occur in the sludge in significant concentrations.

Town officials undertook a study to evaluate the relative economic, environmental, health, and technological merits of various use/disposal options. Two alternatives were eliminated at the outset. Incineration was eliminated because of the poor history of small-scale incinerators, and because of the high capital outlay required, which the town felt unable to raise or justify. Ocean disposal was clearly not an option for this inland town. The three remaining options were land application, distribution and marketing, and landfilling.

Land application appeared to be a highly attractive option. At standard agricultural application rates of 15 dry mt/ha/yr (6.7 dry tons/ac/yr) approximately 6 ha (15 ac) of farmland were needed to apply all the town's sludge. Plenty of productive farmland was available within 32 km (20 mi) of the treatment plant. Some of that farmland was within 8 km (5 mi) of the plant, making transportation of liquid sludge economical. The ability to land apply liquid sludge would save the town the cost of installing and operating dewatering equipment, which would be necessary to produce a higher solids content sludge for transport to more distant areas. Total costs of land application, including transport and application equipment costs, labor, and fuel, were estimated at $100/dry mt. Land application of liquid sludge was therefore an economically attractive option. Local farmers expressed interest in the sludge as a soil conditioner and fertilizer; however, they were concerned about the potential health effects associated with high cadmium concentrations. In addition, the cadmium concentration of 25 mg/kg exceeded the state regulatory limit of 20 mg/kg for land application of sludge to cropland even though it was clearly within the Federal criteria.

Distribution and marketing was not an attractive alternative for several reasons. Although a limited market existed for sludge products among residential homeowners and some farmers, the costs of implementing and maintaining a sludge composting facility, and hiring additional personnel to run the facility and administer the program, were too large. In addition, the cadmium concentration exceeded the state limits for application of sludge to agricultural crops, and the final destination of sludge product would be difficult to monitor and control in a distribution and marketing program.

Landfilling met with some objection. Many of the local citizens opposed the idea of landfilling. The town's sanitary solid waste landfill was going to run out of space within the next 2 years, and, despite the availability of potential landfill sites, the town had not yet been able to site a new sanitary landfill because of public opposition. This opposition stemmed from environmental and public health concerns. Much of the area was underlain by an aquifer from which local drinking water was drawn. Geohydrological conditions would necessitate the installation of liners in a landfill to minimize the potential for groundwater contamination. Because of the environmental concerns, a relatively shallow [1-m (3-ft) depth] wide trench landfill with liners was felt to be the most suitable design. This design had a relatively low sludge loading of 2,000 dry mt/ha (890 tons/ac). For this design, the amount of land needed for the next 20 years of sludge production was estimated to be about 1 ha (2.5 ac). Because landfilled sludge should have about 20 percent solids to reduce leachate formation, dewatering equipment would have had to be installed. Total costs were estimated to be very similar to those estimated for land application.

Land application of the digested liquid sludge appeared to be the most attractive option if the cadmium problem could be eliminated. Municipal officials considered passing an industrial sewer ordinance that would set a maximum level of cadmium in industrial wastewater discharge; this would require the local industry to install pretreatment facilities. Citizens expressed concern that this requirement might cause the industry to relocate, leaving a large proportion of the town jobless. Negotiations were begun with the industry, and a compromise was reached in which the town agreed to assist the industry in finding a suitable pretreatment system. Pilot studies will be run and, when cadmium levels in sludge are adequately reduced, land application will be implemented as the town's primary sludge use method.

However, the long-term storage of any sludge, especially liquid sludge, during the nongrowing season and inclement weather was still a concern. Municipal authorities agreed that another use/disposal option would have to be available as a backup for land application. Landfilling appeared to be a good contingency option. Officials are examining the rate of solid waste generation to see if it would provide sufficient bulk for codisposal of the liquid sludge, and they are investigating the cost of drying beds and mechanical dewatering equipment, which would be necessary for sludge-only landfilling. The officials held preliminary town hearings on the subject because they recognized that a concerted public participation program is necessary for an unpopular option, sludge landfilling, to become a feasible contingency.

9. Trends and Prospects

Sludge management is characterized by extreme complexity. The interplay of technology, public relations, resource management, health and environmental concerns, and economics makes any projections of future sludge management options difficult. Changes in economic conditions and public perception of sludge management, and innovations in process and equipment, modify the way communities evaluate the choices available to them and the basic nature of these options.

New technologies are emerging, including pyrolysis, making bricks from sludge, using sludge for asphalt production, coincineration with municipal waste, earthworm conversion, and recovering precious metals from sludge incinerator ash. The ultimate usefulness of these technologies will depend on many factors, including technical success, environmental soundness, public acceptability, and cost. The history of sludge management suggests that new ideas are accepted only cautiously. Processes that employ biological systems similar to those that take place during natural decay of wastes have generally proven the most successful options. Composting is one example of this.

Research into the health and environmental effects of sludge use/disposal helps to provide more refined management techniques to prevent, detect, and resolve problems. This information will enable future Federal requirements for sludge management to specify planning techniques and operating procedures in greater detail than in the past. While this will impose some constraints on the options available to states and municipalities, it may also permit higher sludge use/disposal rates, with close and careful scrutiny for the environmental or health effects. In response to these more specific Federal guidelines, local governments will probably rely more on advanced planning. States will also be refining their programs to include Federal technical requirements, and to require more specific local government planning.

Changes in public attitudes will also have a dramatic effect on future sludge management options. The Federal emphasis on sludge use as a resource rather than as a waste may provide subtle pressure to alter public attitudes and clarify the distinction between municipal sludge and industrial wastes. As EPA regulation of industrial discharges to sewers takes effect, the concentration of metals and toxic organic chemicals in sludge should decline, making its use in agriculture more economical and more acceptable to the general public. Consequently, land application will become even more prevalent in the future.

Public acceptance is crucial to the success of any sludge management technique and cannot be secured solely by technical improvements or research into health effects. Careful and enlightened state regulation of sludge use and disposal will be essential to improved public perception of sludge management. However, the largest responsibility for fostering favorable public attitudes lies with local operating agencies and their contractors. A history of responsibility and concern in the execution of sludge management will go far towards clearing the way for any future changes.

10. Sources of Further Information

Additional documents provide further guidance or information on the various aspects of sludge management discussed in this guidance document. The additional documents for each chapter are listed below. To obtain further guidance, contact the EPA sludge coordinators in the EPA regional offices (Table 17), and the state agency responsible for sludge management.

2. Municipal Sludge

EPA. 1979. Environmental pollution control alternatives. EPA 625/5-79-012. Center for Environmental Research Information, U.S. Environmental Protection Agency, Cincinnati, Ohio.

3. Land Application

EPA. 1980. A guide to regulations and guidance for the utilization and disposal of municipal sludge. EPA 430/9-80-015. Office of Water, U.S. Environmental Protection Agency, Washington, D.C.

EPA. 1983. Technology Transfer process design manual: land application of municipal sludge. EPA-625/1-83-016. Center for Environmental Research Information, U.S. Environmental Protection Agency, Cincinnati, Ohio.

EPA/FDA/USDA. 1981. Land application of municipal sewage sludge for the production of fruits and vegetables: a statement of Federal policy and guidance. SW-905. Office of Solid Waste. U.S. Environmental Protection Agency; U.S. Food and Drug Administration; and U.S. Department of Agriculture, Washington, D.C.

National Fertilizer Development Center, Tennessee Valley Authority, Muscle Shoals, Alabama.

Table 17. EPA Regional Sludge Coordinators

REGION I
Municipal Facilities Branch
Water Division
EPA — Region I
JFK Federal Building
Boston, MA 02203

REGION II
NY Project Management Station
Water Division
EPA — Region II
26 Federal Plaza
New York, NY 10007

REGION III
Water Division
EPA — Region III
6th and Walnut Streets
Philadelphia, PA 19106

REGION IV
Facility Requirement Branch
Water Management Division
EPA — Region IV
345 Courtland Street, NE
Atlanta, GA 30308

REGION V
Water Division
Facility Planning, Unit 1
EPA — Region V
230 South Dearborn Street
Chicago, IL 60604

REGION VI
Water Division
EPA — Region VI
First International Building
1201 Elm Street
Dallas, TX 75270

REGION VII
Construction Grants Branch
Water Division
EPA — Region VII
324 East 11th Street
Kansas City, MO 64106

REGION VIII
Water Management Division
EPA — Region VIII
1860 Lincoln Street
Denver, CO 80295

REGION IX
Water Division
EPA — Region IX
215 Fremont Street
San Francisco, CA 94105

REGION X
Construction Grants Section
Water Division, Mail Stop 429
EPA — Region X
1200 6th Avenue
Seattle, WA 98101

4. Distribution and Marketing

EPA. 1981. Composting processes to stabilize and disinfect municipal sewage sludge. EPA 430/9-81-011. Office of Water Program Operations, U.S. Environmental Protection Agency, Washington, D.C.

Hornick, S.B., L.J. Sikora, S.B. Sterrett, J.J. Murray, P.D. Millner, W.D. Burge, D. Colacicco, J.F. Parr, R.L. Chaney, and G.B. Willson. 1984. Utilization of sewage sludge compost as a soil conditioner and fertilizer for plant growth. Agricultural Information Bulletin 464. Agricultural Research Service, U.S. Department of Agriculture, Beltsville, Maryland.

MES. 1984. Operations manual for sewage sludge composting: Blue Plains wastewater treatment plant. Maryland Environmental Service, Annapolis, Maryland.

USDA/EPA. 1980. Manual for composting sewage sludge by the Beltsville aerated-pile method. EPA-600/8-80-022. Agricultural Research, Science, and Education Administration, U.S. Department of Agriculture, Washington, D.C.; and Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio.

5. Landfilling

Byers, H.W., and G.D. Lukasik. 1983. Design, operating and monitoring a sanitary landfill for the exclusive disposal of wastewater treatment plant sludges. North Shore Sanitary District, Gurnee, Illinois.

EPA. 1978. Technology Transfer process design manual: municipal sludge landfills. EPA 625/1-78-010. Center for Environmental Research Information, U.S. Environmental Protection Agency, Cincinnati, Ohio; and Office of Solid Waste, U.S. Environmental Protection Agency, Washington, D.C.

6. Incineration

Bennett, R.L., K.T. Knapp, and D.L. Duke. 1984. Chemical and physical characteristics of municipal sludge incinerator emissions. EPA 600/3-84-047. NTIS PB-84-169 325.

EPA. 1979. Technology Transfer process design manual: sludge treatment and disposal. EPA 625/1-79-011. Municipal Environmental Research Laboratory and Center for Environmental Research Information, U.S. Environmental Protection Agency, Cincinnati, Ohio.

EPA. 1984. Technology Transfer seminar publication on municipal sludge combustion. Center for Environmental Research Information, U.S. Environmental Protection Agency, Cincinnati, Ohio.

Gerstle, R.M., and D.N. Albrinck. 1982. Atmospheric emissions from sewage sludge incineration. J. Air Pollution Control Assoc. 32(11):1119-1123.

Wall, H.O., and J.B. Farrell. 1979. Particulate emissions from municipal wastewater sludge incinerators. Presented at Mid-Atlantic States Section, Air Pollution Control Association, Newark, New Jersey, April 27, 1979.

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Duke, T.W. (ed.). 1982. Impact of man on the marine environment. EPA 600/8-82-021. Office of Research and Development, U.S. Environmental Protection Agency, Washington, D.C.

EPA. 1984. Report to Congress January 1981-December 1983. On Administration of the Marine Protection, Research, and Sanctuaries Act of 1972, as Amended (P.L. 92-532) and Implementing the International London Dumping Convention. Office of Water Regulations and Standards, U.S. Environmental Protection Agency, Washington, D.C.

Goldberg, E. (ed.). 1979. Proceedings of a Workshop on Assimilative Capacity of U.S. Coastal Waters for Pollutants. National Oceanographic and Atmospheric Administration, Washington, D.C.

NAS. 1976. Disposal in the marine environment. An oceanographic assessment. Commission on Natural Resources, National Academy of Sciences, Washington, D.C.

NRC/NAS. 1983. Report of the Workshop on Land, Sea, and Air Disposal of Industrial and Domestic Wastes. Board on Ocean Science and Policy, National Research Council and National Academy of Sciences, Washington, D.C.

NOAA. 1975. Ocean dumping in the New York Bight. NOAA Tech. Rept. ERL 321-MESA.

8. Evaluating Alternatives

EPA. 1980. Innovative and alternative technology assessment manual. EPA 430/9-78-009. Office of Water Program Operations, U.S. Environmental Protection Agency, Washington, D.C.; and Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio.

EPA. 1980. Evaluation of sludge management systems: evaluation checklist and supporting commentary. EPA 430/9-80-001. Office of Water Program Operations, U.S. Environmental Protection Agency, Washington, D.C.

11. References

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